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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

MBA PROFESSIONAL REPORT

'Helios Dynamics"
A Potential Future Power Source for the Greek Islands

By: Ioannis Deligiannidis
Ioannis Angelis

June 2007

Advisors: Ron Tudor
Jeffrey Cuskey

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*

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1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2007	**3. REPORT TYPE AND DATES COVERED** MBA Professional Report

4. TITLE AND SUBTITLE "Helios Dynamics" A Potential Future Power Source for the Greek Islands	**5. FUNDING NUMBERS**
6. AUTHOR(S) Ioannis Deligiannidis, Ioannis Angelis	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School, Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER** N/A

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

The use of Alternative Renewable Energy Sources is becoming an increasing possibility to satisfy the energy demands of the future. Environmental concerns, economic benefits but most of all the potential exhaustion of the current sources of energy, such as fossil fuels, have alarmed the international community and gave incentives for the promotion of other energy forms. In this demanding environment, Photovoltaics stand as a promising solution for the electrification of large portion of the population. Especially in the case of the off grid sites, such as the Greek islands, this solution promises to give an end to the reliance on the costly, and environmentally harmful use of oil as the only means of energy production.

The objectives of this Master of Business and Administration (MBA) project are to 1) Examine the country's current energy policies and legal environment as it relates to energy production and delivery to off grid islands 2) Provide a Cost Benefit Analysis of shifting to PV Energy and 3) Build a preliminary body of knowledge to facilitate future research involving the development of new PV technologies in remote locations.

We estimate that this study will help the cause of broadening the use of Renewable Energy Sources (RES).

14. SUBJECT TERMS: Off Grid Islands, Renewable Energy Sources, Photovoltaics, Diesel-driven Generators, Legislation, Atira Technology	**15. NUMBER OF PAGES** 93
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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"HELIOS DYNAMICS" A POTENTIAL FUTURE POWER SOURCE FOR THE GREEK ISLANDS

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
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“HELIOS DYNAMICS” A POTENTIAL FUTURE POWER SOURCE FOR THE GREEK ISLANDS

ABSTRACT

The use of Alternative Renewable Energy Sources is becoming an increasing possibility to satisfy the energy demands of the future. Environmental concerns, economic benefits but most of all the potential exhaustion of the current sources of energy, such as fossil fuels, have alarmed the international community and gave incentives for the promotion of other energy forms. In this demanding environment, Photovoltaics stand as a promising solution for the electrification of large portion of the population. Especially in the case of the off grid sites, such as the Greek islands, this solution promises to give an end to the reliance on the costly, and environmentally harmful use of oil, as the only means of energy production.

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ACKNOWLEDGMENTS

We would like to express our sincere and warm thanks to Professor Ron Tudor, Leader Advisor and Lecturer Jeffrey Cuskey, Support Advisor for their help, guidance support and patience during the course of this research effort. Their invaluable assistance and attention to detail contributed to the success of the completion of this study.

Additionally we would like to thank our families, for their love, and understanding during the trying days of this research effort. Their support was essential in this MBA project being successfully completed.

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I. INTRODUCTION

A. PREFACE

Greece, a country the size of the State of Alabama, has about 3000 islands of which 200 are populated. The majority of these 200 islands is far off the mainland's coast and is not linked to the country's main electricity grid. These islands depend on imported diesel fuel and diesel fired generators for the majority of their energy needs. Tourism in the summer is the most important economic activity for these islands. Energy demand to support tourism and air-conditioned buildings is high during the summer months. Providing electricity via diesel generators is highly inefficient and produces a lot of carbon dioxide and pollution. In the past, the Greek Government has evaluated the use of Renewable Energy Sources (RES), such as solar and wind power systems. However, they were rejected for not being economically viable solutions due to high initial investment costs.

B. RESEARCH OBJECTIVES

This study identifies the strengths and weaknesses of Greece's current energy policy for the off-grid Greek islands and evaluates if a change due to modern Photovoltaic (PV) technology is economically feasible. Additionally, this study:

(1) Examines the country's current energy policies and legal environment as it relates to energy production and delivery to off grid islands.

(2) Provides a Cost Benefit Analysis of shifting to PV Energy; and

(3) Builds a preliminary Body of Knowledge to facilitate future research involving the development of new PV technologies in remote locations.

C. RESEARCH QUESTIONS

1. Primary Research Question

What are the significant issues concerning the production of electricity in the off-grid islands from diesel driven generators?

2. Secondary Research Question

Does the use of PV electricity generation plants provide an economically viable alternative to current electricity generation methods?

3. Third Research Question

Are there any investment opportunities from new PV technology as a result of recent deregulation of energy production in Greece?

D. SCOPE AND ORGANIZATION

This project examines the integration and application of the emerging Photovoltaic alternative energy to provide electricity production in off grid islands of the Aegean Archipelagos in Greece. Particularly, it is going to be analyzed the cost benefit attraction of the use of Photovoltaic panels with the Atira® tech. Photovoltaic Power Converter technology embedded.

E. METHODOLOGY

The research methodology for this project consists of:

- A cost benefits analysis of the two energy solutions and a case study for Amorgos, a central Aegean island of Greece. These results will be a body of knowledge to enable larger scale conclusions to be drawn regarding the potential application of PV technologies.

F. EXPECTED BENEFITS

This research will offer an apparent understanding of the capabilities of the emerging Photovoltaic Power Converter (PVPC) technology used in panels for electricity production in the Aegean off grid islands of Greece. Greece has to change the energy policy in these islands for many reasons and this study will demonstrate the economic viability of the use of Photovoltaics given the great photovoltaic potential of the islands due to their geographical position.

II. THE ENERGY BACKGROUND OF GREECE

A. GEOGRAPHICAL AND OTHER GENERAL DATA

Greece, officially the Hellenic Republic of Greece, is a small country in Southern-Eastern Europe, situated on the Southern end of the Balkan Peninsula. Greece has an area of 131,940 sq. km., which makes it slightly smaller than the size of the State of Alabama. Greece lies at the juncture of Europe, Asia and Africa. It is bordered by Bulgaria, the Former Yugoslav Republic Of Macedonia (FYROM) and Albania to the north and by Turkey to the east. The Aegean Sea lies to the east of the mainland of Greece, while the Ionian Sea lies to the west. According to the National Statistical Service of Greece (NSSG), in 2006, Greece had a total population of 11,082,752 of whom 5,508,165 were male and 5,617,014 female.[1]

Greece consists of a mountainous and craggy mainland jutting out into the sea at the southern end of the Balkans. It has the Peloponnesus peninsula and numerous islands (around 2,000), including Crete, Euboea, Lesvos, Chios, the Dodecanese and the Cycladic groups of the Aegean Sea as well as the Ionian Sea islands. Greece has the 10th longest coastline in the world with over 15,000 kilometers; its land boundary is 1,160 kilometers (721 miles).[2]

The climate in Greece is typical of the Mediterranean climate: mild and rainy winters, relatively warm and dry summers, and, generally, extended periods of sunshine throughout most of the year. The winters are milder in the islands compared to the mainland. During the warm and dry period, the weather is usually stable, the sky is clear, the sun is bright and there is generally no rainfall.

1 General Secretariat of National Statistical Services of Greece, http://www.statistics.gr/eng_tables/S201_SPO_5_TS_91_06_4_Y_EN.pdf, p. 3 Last Accessed: June 2007.

2 Wikipedia, http://en.wikipedia.org/wiki/Greece, Last Accessed: June 2007.

The tourism industry, especially in the Greek islands, is a major source of exchange earnings and revenue. Tourism accounts for the 14.3% of the country's Gross Domestic Product (GDP) and for employing 16.5% of the total population. Greece welcomed almost 20 million visitors in 2006.

Figure 1. General map of Greece[3]

[3] Greek Travel, http://www.greektravel.com/maps/map1.jpg, Last Accessed: June 2007.

B. NATURAL ENERGY RESOURCES

Greece has limited primary energy sources, which, apart from coal (lignite) do not contribute significantly to the national energy balance. The oil and gas fields discovered in the early seventies were relatively small and are being rapidly depleted, while the available potential renewable energy is yet to be developed. Furthermore, Greece is highly dependant on imported petroleum, which accounts for almost 69% of its primary energy supply. Indigenous, brown coal (lignite) contributes 32% to the energy supply with the balance stemming from renewable energies, mainly hydro-electric and biomass. Domestic oil and gas also provide a small proportion of the overall energy production. Greece has no nuclear power plants, due to its high potential for seismic activity.

1. Solid Fuels

Coal reserves are estimated at 2.7 billion tons. Lignite is the main type of solid fuel used in Greece. (Lignite is generally considered the lowest rank of coal, having one of the lowest energy potentials while having one of the highest pollution potentials).[4] The Institute of Geological and Mineral Exploration (IGME), has exclusive right to explore for lignite and other mineral deposits in Greece while the Greek State has exclusive rights over the development and exploitation of lignite deposits. Except for a few private lignite-mining operators, the state has assigned all rights to the Public Power Corporation (PPC), at no charge. The PPC has priority in the development and exploitation of all coal-fields. Ninety-nine percent of the lignite consumption is used for power generation.

2. Oil

The Greek State owns the petroleum and other hydrocarbon sources. In turn, the State administers its right to explore, develop and produce fields through the Hellenic Petroleum Corporation (HP), a public company that is responsible for all activities relating to crude oil and oil products. A 20% share of the company was privatized in

[4] Wikipedia, http://en.wikipedia.org/wiki/lignite_coal, Last Accessed: June 2007.

1998, while 80% remains in the hands of the State. The Hellenic Petroleum Corporation can lease exploration and exploitation areas to third parties on the basis of royalty/income tax contracts. Crude petroleum is extracted in the off-shore Prinos Field, near the island of Thasos in the northern Aegean Sea. Oil production in Greece, has been declining steadily since it peaked at 25,000 bbl/d in the mid 1980's. In 2005, less than 4000 bbl/d of oil were daily produced. The largest refinery is the Aspropyrgos Refinery near Athens, which has a capacity of 125,000 barrels of oil per day.[5]

3. Natural Gas

In 1987, Greece decided to introduce natural gas into its energy system and supply contracts for the importation of natural gas were signed. The Public Gas Corporation (DEPA) is a public company that has a monopoly for importation, transmission and storage of natural gas in Greece. It is also partially involved in its distribution. To date, natural gas is distributed in a limited fashion in Greece as the distribution networks are still under construction.[6]

4. Renewable Energy Sources (RES)

The Centre for Renewable Energy Sources (CRES) is the state institution that is responsible for the promotion of Renewable Energy Sources and Energy Efficiency in Greece. To date, the Public Power Corporation (PPC) has been almost the exclusive source of renewable electricity in Greece. It owns all the large hydro-power stations, 97% of the small hydro-power capacity, and 72% of photovoltaic capacity. Changes in support measures for RES are likely to increase the role of non-PPC generators in renewable energy supply. The renewable energy sources listed in order of importance are wind energy, small hydro-power plants, biomass and possibly photovoltaic installations.

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[5] Institute of Greek Industry Labor, http://www.inegsee.gr/pdxb/Aktiv/Erevna/Fotinopulu/Elda/kef1-6.htm, Last Accessed: June 2007.

[6] Greek Gas Company, http://www.depa.gr/gr/main.html, Last Accessed: June 2007.

C. ENERGY SECTOR

The energy sector in Greece is experiencing a very interesting transitional period. New networks are being created and new intergovernmental regional markets are being established. Europe and the lands immediately to its east are establishing closer relations. Because of this, Greece stands, geographically at the crossroads, which means it can play a significant, important role in the area of energy issues, and could be significantly influenced by EU policies.

The energy policy of the European Union (EU) already has influenced the energy sector in Greece, despite the divergences in the timetable of application of reforms. The recent legislative developments in the electricity production denationalization can accelerate further the reform of the energy sector in Greece.

1. Energy Supply

In 2004, the total Protogenic Energy Supply (TPES) reached the 33 Millions of tons of oil equivalent Mtoe.[7] This is an increase of 48% concerning the level of 22 Mtoe 1990. The TPES has been increased on average 2.3% per year between 1990 and 2003, but was increased at 9.5% between 2003 and 2004. The increase of TPES it is forecasted from the Greek government to raise at an average 1.4% between 2004 and 2010, something that reflects the efforts towards energy efficiency and the substitution of lignite and oil with the further penetration of natural gas in the Greek economy.

The most important change in the energy mixture of TPES is the change from lignite to natural gas. The lignite was calculated in 8 Mtoe of (36% of TPES) in 1990 and 9 Mtoe (28%) in 2004, presenting a fall of 23%. Natural gas was introduced in the energy mix of Greece in 1995, and since then its use has been increased considerably, by 0.14 Mtoe (0.6%) in 1990 in 2.23 Mtoe (6.8%) 2004.

[7] The International Energy Agency defines: one toe to be 10 Gcalth, equal to 41.868 GJ or 11.625 MWh.

The participation of oil in the TPES was also increased by 12.8 Mtoe (58%) in 19.5 Mtoe (59.5%). This fact, in conjunction with the continuously rising oil prices has a direct impact on many other sectors of the Greek economy, like transportation retail trade and tourism.

The share of all renewable sources of energy in the TPES remained constant, with 5% on the TPES, between 1990 (1.1 Mtoe) and 2004 (1.6 Mtoe). Because of the share of big hydroelectric construction projects, the production of renewable energy can differ considerably from year to year. Especially this year (2007), it is forecasted to be much lower because of the softer winter and the decreased rainfalls.

2. Energy Demand

In 2004, Greek Total Final Consumption (TFC) reached 23.5 Mtoe, showing an increase of 52% compared to the 15.5 Mtoe that were consumed 1990. The total final consumption was increased at 2.6% per year in the period from 1990 to 2003 and at 8.8% between 2003 and 2004. The Greek government expects that it will be increased only at 0.5% per year for the period 2004-2010, because of the increased investments in the energy efficiency and the substitution of fuels. The participation of oil in the total final consumption (TFC) was increased by 11 Mtoe (69.5%) in 17 Mtoe (72%) between 1990 and 2004. The consumption of oil increased to 58% during the same period.

The next fuel in total final consumption (TFC) is electricity, which contributed 4.3 Mtoe in 2004, presenting an increase 75%, concerning the 2.45 Mtoe in 1990. The contribution of electricity in total final consumption (TFC) was increased very little by 16% to 18%. The renewable sources of energy contributed 0.95 Mtoe in 1990 and reached the 1.06 Mtoe in 2004, so this decreased their share in total final consumption (TFC) from 6.2% in 4.5%.[8]

[8] Greece – In-Depth Review, © OECD/IEA, 2006.

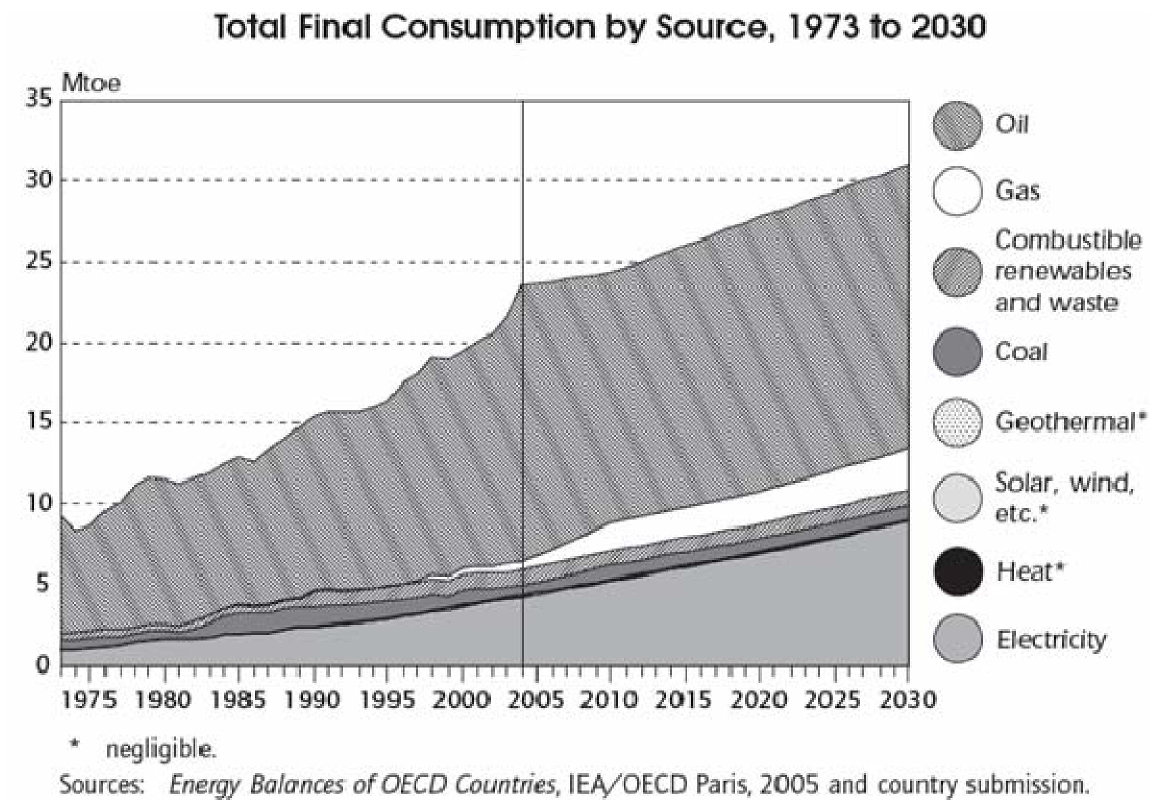

Figure 2. Energy Total Final Consumption in Greece 1973-2030

D. ELECTRICITY

1. Supply

The Greek production of electricity increased rapidly from 1990, when it was 35 Tera Watt hours (TWh). In 2004, it reached in 59TWh, a total increase of 69% since 1990, with annual medium increase of order 3.8%. The main increase emanated from stations of generation of electricity of coal (lignite), which produced 25 TWh in 1990 and 36 TWh in 2004, presenting increase 41%. The most important change in the mix of fuels was the start of electricity production with natural gas, which did not exist in Greece in 1990, and contributed 9 TWh in 2004. In this same period, the supply of electric energy was differentiated, with the share of lignite decreasing from 72% of total mixed production in 1990 to 61% in 2004.[9]

[9] Greece – In-Depth Review, © OECD/IEA, 2006.

2. Demand

The demand of electric energy in Greece increased rapidly from 1990. The basic increase was observed in all the sectors: domestic, commercial, rural, etc.

In 2003, the domestic sector was the biggest consumer of electric current in Greece, with 16.4 TWh annual consumption - an increase of 81% compared to 1990, when it was 9.1 TWh. While the industry sector was the bigger consumer in 1990, with 12.1 TWh, it fell to third place in 2003, when it consumed 14.2 TWh - an increase of 17%.

In 2003, the commercial sector exceeded the industrial sector and became the second largest consumer of electricity in Greece. It consumed 15 TWh, compared with 5.6 TWh in 1990, a medium annual increase of 8%, and a total increase of 167% over the entire period, this energy consumption reflects the increase that took place in the Greek economy over the same interval of time.

3. History of Electricity in Greece

Electricity “came” to Greece in 1889. The General Contracting Company built the first electrical power plant in Athens and the Palace was the first building to be illuminated. Electrical lighting was very soon spread to the capital's historical centre. Thessaloniki, Greece’s second biggest city, at the time still under Turkish occupation, was to see electrical light in the same year, when a Belgian Company was commissioned by the Turkish authorities to build an electricity plant to illuminate the city and power the tram system.

Later on, multinational electricity corporations began to appear in Greece. The American company Thomson - Houston, with the participation of the National Bank of Greece, founded the Hellenic Electricity Corporation which undertook to supply electricity to other major towns in Greece.

By 1929, 250 towns with a population of over 5000 were supplied with electrical power. In the most remote areas, where major companies found it unprofitable to build electrical power stations, the supply of electricity was undertaken by individuals or

municipal and community authorities using small-scale plants. In 1950, there were about 400 companies in Greece engaging in the production of electrical energy. As raw material, they used oil and coal which, of course, were both imported from abroad.

This fragmented production, combined with the fact that fuel had to be imported, pushed the price of electricity to high levels (three or even five times higher than the prices prevailing in European countries). Electricity was thus a luxury good, although in most cases it was supplied only at certain times in the day and sudden power outages were quite common.

4. Foundation of the Public Power Corporation (PPC)

In order for electrical power to spread uniformly throughout Greece and be effectively utilized both in industry and in the country, the Greek government created the Public Power Corporation (PPC) in August of 1950. The new company's focus was:

- Utilization of the national resources required, which entailed huge investments that could not be undertaken by individual power producers.
- Consolidation of production to a single interconnected system which would ensure that loads would be allocated on a national scale.
- Creation of a single organization which would enable the allocation of cost between profitable and loss-making areas.

The PPC came to satisfy all these tasks in a successful way and was established to operate 'in the interests of the public' with an aim to develop and implement a national energy policy through the intensive exploitation of domestic resources, which would enable every Greek citizen to enjoy electrical power at the lowest possible price.

Immediately upon its establishment, the PPC focused on the utilization of domestic energy resources and the consolidation of the networks to the national energy interconnected system. The rich lignite deposits, which had already been discovered in the Greek subsoil, began to be mined and used as fuel in the lignite power stations which the PPC set up. At the same time, the Corporation began to utilize the power of water through the construction of hydroelectric stations at the country's major rivers.

PPC was reformed in 2001, with the transformation of a government owned company, into a company that is listed on the Athens and London Stock Exchanges. Today, 51% of the company belongs to the Greek State, 45% is held by public and institutional investors, and 4% belongs to the actuarial institution of employees of the company.

In the past, the PPC existed profitably, with a functional margin of profit of roughly 15% in 2003 and 16% 2004. However, in 2005 the net profit of the company was reduced 54% because of the need to purchase credits for CO_2 emissions from the international market under the new environmental standards. Greece as a full member of the Kyoto Protocol has a limited amount of CO_2 tons that they can produce yearly, a number that decreases year by the year. The company paid 12.6 Million Euros in order to buy CO_2 permits for 2005. Even worse, in 2006 the company's net profit was reduced 83% in comparison with 2005. This was mainly due to the increased fuel prices from the two month summer war in the Middle East and again from the purchase of CO_2 permits from the international market. In 2006 the company paid a total of 10.1 Million Euros for CO_2 permits.[10]

The profitability of the PPC depends exclusively on the decisions of the government for the price of electricity, as their ability to recover expenses depends on the height of prices that are allowed by the government for the consumers (which do not have a choice). According to the current governmental proposals and legislation, the sovereign place of the PPC in the Greek electricity production industry will be decreased progressively in the next few years. With the latest legislation (July 2006) for the deregulation of electricity production, new companies emerged using mainly natural gas as their fuel. However, none of these companies has yet started production and supply of electricity.

[10] Euro2day.gr, http://www.euro2day.gr/articles/125880/, Last Accessed: June 2007.

5. Electricity Production from Lignite

The calorific content of lignite is three to seven times lower than that of black coal and five to seven times more than oil. However, just because of its generous existence in Greece and in the absence of a better solution, in the 1950s it was decided that the country's energy needs should be based on.

For this purpose two main Energy Centers (facilities) were established to use lignite as a fuel. The biggest one is West Macedonia (1951) and later (1969) another one was established in Megalopolis in Southern Greece. The typical efficiency of the Greek plants is around 33%, but another 3.5% is lost in distribution.

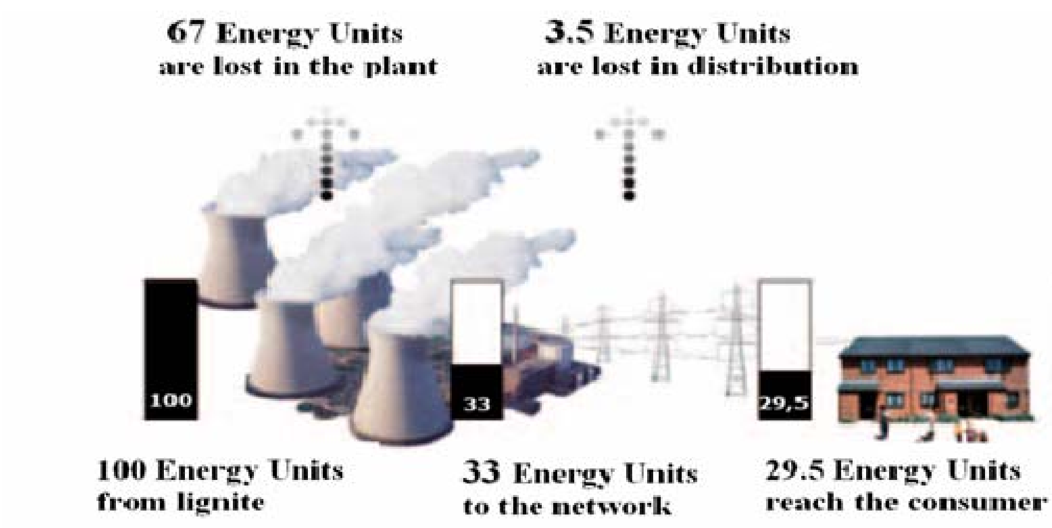

Figure 3. Efficiency of a typical Greek lignite power plant[11]

It must be mentioned that in the latter facility in Megalopolis the PPC excavates and utilizes the lowest efficiency lignite anywhere in the world for the production of electricity. The calorific power of this lignite is 1,050-1,100 Kcal/kg, while the Macedonian lignite's power is 1,800 – 2,300 kcal/kg.

[11]Greenpeace Greek Branch, http://www.greenpeace.org/raw/content/greece/press/118523/lignitis.pdf, Last Accessed: June 2007.

This inefficiency, however, creates another big problem - increased CO_2 emissions. The following table shows the amount of CO_2 produced for each KWh that was created in these plants.

CO_2 emissions grams per kilowatthour (gr.CO_2/kwh) in Greek lignite plants	
Northern Greek Lignite	**1,310**
Southern Greek Lignite	**1,490**
Greek Average	**1,346**
For Comparison:	
Oil	**750**
Natural Gas	**430**

Table 1. CO_2 emissions in the Greek lignite plants

The Greek government agreed with the Convention of the United Nations in 1994 and signed the Kyoto Protocol, ratifying the protocol in 2002 with N.3017/2002. Accordingly, also in line with the agreement of the European Union on the distribution of pollutants from 1998, Greece will be required to limit the increase of emissions of greenhouse gases to a level not greater than 25% of the level of the base year (1990).

This is a very big problem for PPC and Greece because from 2006 they will be forced to buy expensive CO_2 permits from the International Trade. Nevertheless, there are also a dozen other dangerous gases that are produced by this approach of electricity production like CO, SO_2, NOx, arsenic, and many others.

According to the National Institute of Geological Research (NIGR) the lignite reserve of Greece is now about 6.7 billion tons of which 3.3 billion tons are estimated to be exploitable for electricity production. This means that with an optimistic calculation the Macedonian lignite is sufficient for forty years and that of Megalopolis is for only twenty years more. The Macedonian lignite center is so big that every minute, one hundred tons of lignite are consumed for electricity production. Today, PPC's eight

lignite power stations comprise 43% of the country's total installed capacity and produce nearly 61% of the country's electrical energy. The total thermoelectric plant capacity of Greece is 5288 MW and in 2005 the total electricity produced by them was 31,977 GWh, which is 61% of the total electricity production of the PPC.

Greece also has a small number of hydroelectric plants, some natural gas production stations, and some Renewable Energy Sources. The total installed capacity of the 97 PPC power plants is currently 12,276 MegaWatts (MW) with a net generation of 52.9 TWh in 2005.

INSTALLED POWER PLANT CAPACITY (MW) OF GREECE (31/12/2005)							
	THERMOELECTRIC				**OTHER**		
	LIGNITE UNITS	OIL UNITS	NATURAL GAS	TOTAL THERMO	HYDRO PLANTS	R.E.S. PLANTS	TOTAL
GRID CONNECTED	5.288	750	1.581	7.619	3.060	7	10.686
CRETE, RHODES AND OTHER SMALLER OF GRID ISLANDS	-	1.559	-	1.559	1	30	1.590
TOTAL	9.178				3.061	37	12.276

Table 2. Installed Power Plant Capacity (MW) of Greece in 2005[12]

[12] Greek Public Power Corporation, http://www.dei.gr/ecportal.asp?id=2610&nt=101&lang=2&fig=261, Last Accessed: March 2007.

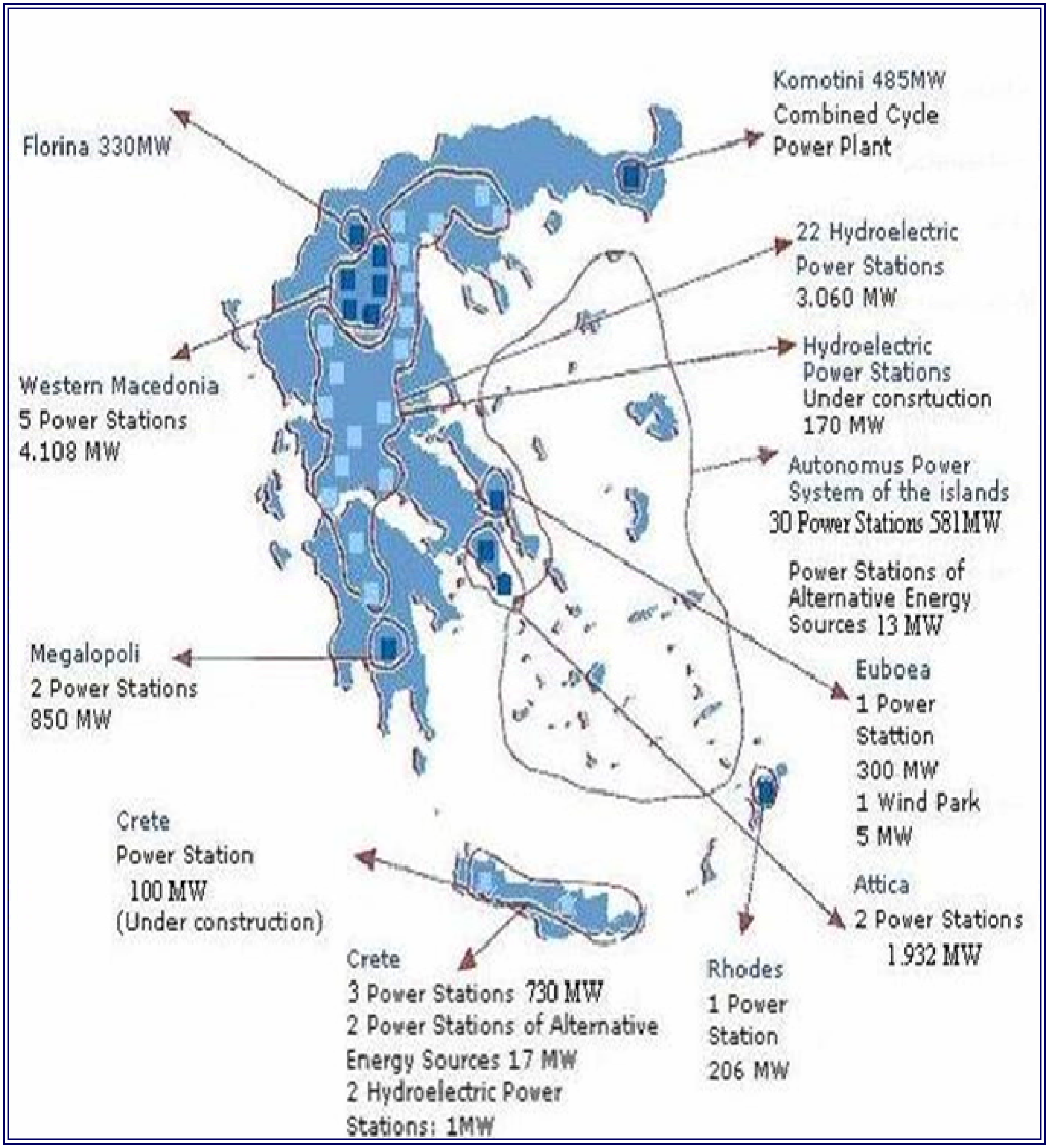

Figure 4. Map of Power Plants of Greece (2005)[13]

[13] Greek Public Power Corporation, http://www.dei.gr/ecportal.asp?id=146&nt=123&lang=2, Last Accessed: June 2007.

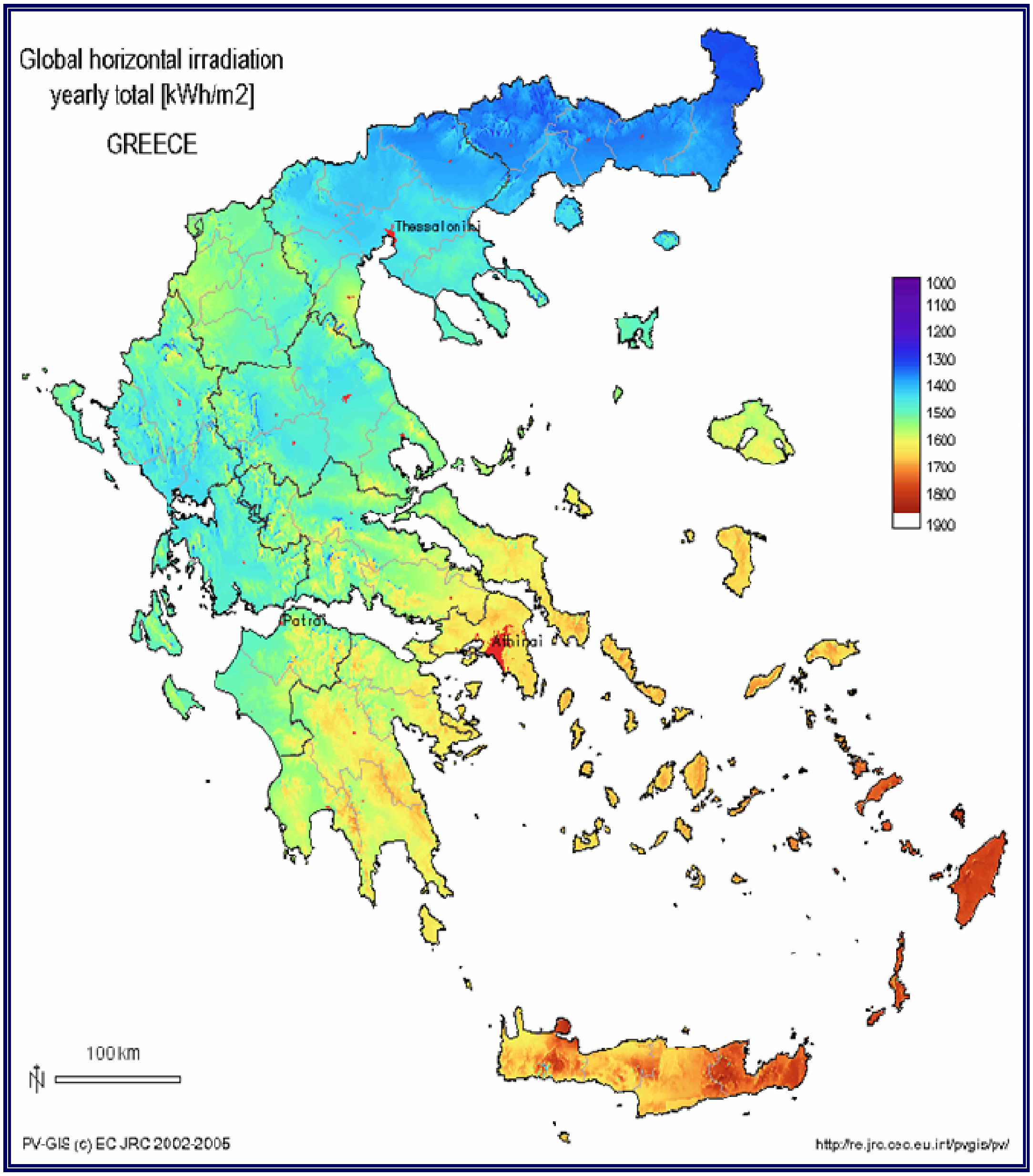

Figure 5. Solar irradiation in Greece (kwh/m^2) per year[14]

[14] European Commission Joint Research Centre, http://re.jrc.ec.europa.eu/pvgis/countries/europe/g13y_gr.png, Last Accessed: June 2007.

The total capacity of PPC in the Aegean islands consists of 60 autonomous power plants located on Crete, Rhodes and the other smaller Greek islands (33 thermal (oil), two hydroelectric, 18 wind and five photovoltaic parks). The total installed capacity in those stations is over 1,559 MW of electricity.

6. Energy Policy in the Off-Grid Islands (O.G.I.)

Islands represent a unique challenge in terms of energy supply. A great deal of work as been carried out on this specific aspect of energy supply on different islands in the world. Unfortunately due to island specific energy use, profile, resources and different kinds of environmental conditions, a study of one island cannot be easily applied to other islands. The Aegean group of islands of Greece is one of the two major groups of islands in Greece. The other group, (the Ionian Islands), in the West part of Greece are connected with the main Grid and to each other due to the relatively smaller distance from the mainland and between them. The Aegean group consists of about 100 populated islands including Crete and Rhodes. The smallest is only a few hundreds square meters while Crete is 8.336 km² and the population that lives on them is nearly one million people. However, this number increases in the summer period due to the tourists that visit them. The climate is warm and the average rainfall is 400 mm per year. The temperature varies from 22 Celsius to 39 Celsius during summer and 11 to 30 for the rest of the season. The yearly average solar radiation over the Aegean is 1500-1700 Kwh/m2.

The Aegean off-grid islands correspond roughly to 8% of total Greek demand for electric energy. The Greek government follows a policy towards the interconnection of more from these islands, where this is technical and economically feasible. The cost of production, distribution and supply of electricity in these islands is very high, compared to the corresponding cost in the continental country because of the use of diesel generators. However, the cost to power the islands is averaged into the total cost for Greece, meaning the mainland consumers subsidize the islands.

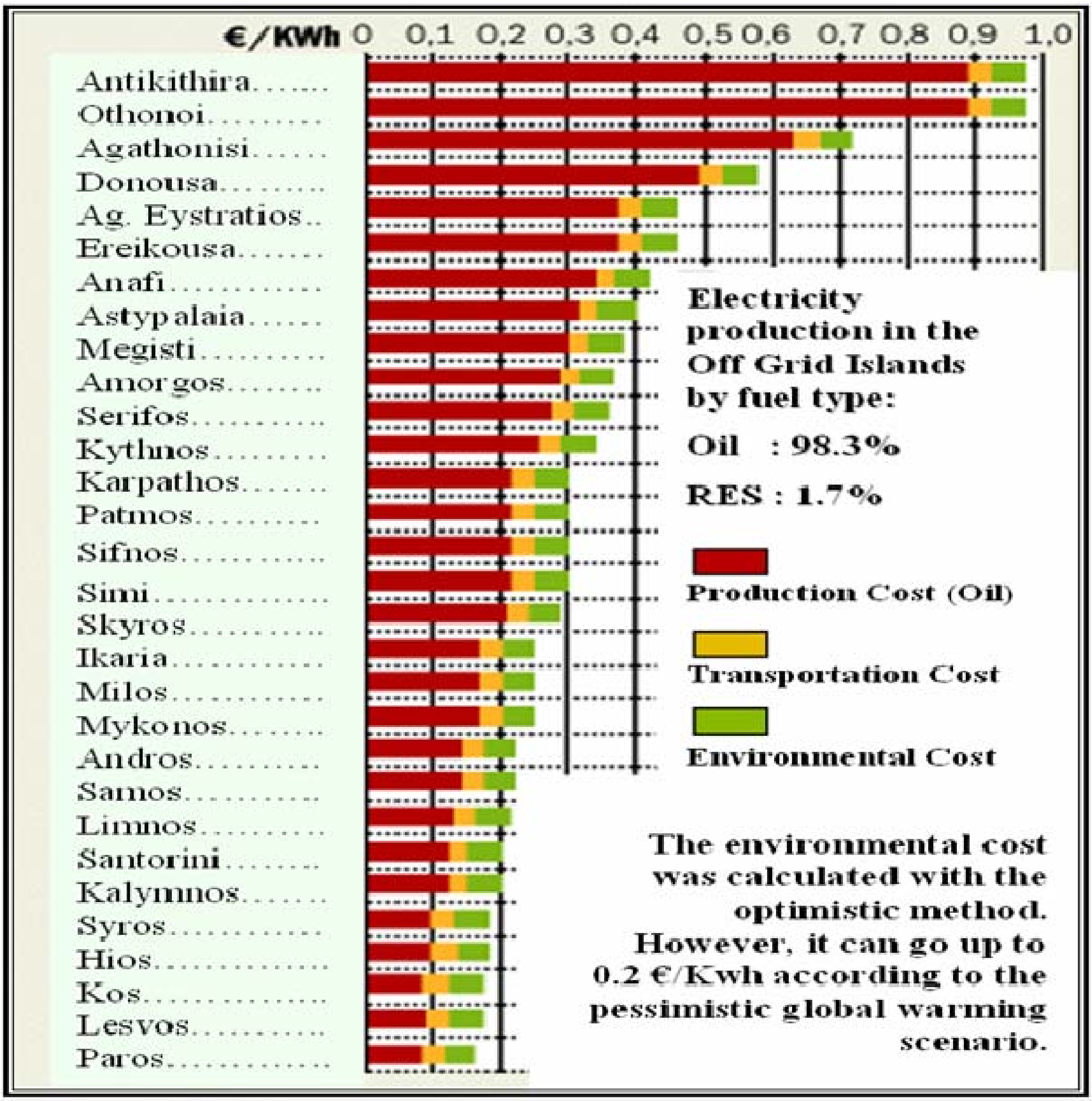

Figure 6. Electricity cost in the off grid islands[15]

Considering the remoteness of the islands and the polluting nature of the existing plants, it is highly desirable to adopt a strategy to utilize the available potential of non-polluting renewable energy sources for these ecologically sensitive islands.

15 "Ta Nea" daily newspaper, http://data.tanea.gr/D2005/D0514/1el24a.gif, Last Accessed: March 2007.

7. Economical and Environmental Consequences of This Policy

The PPC is the general administrator of the whole network, exclusive supplier and unique producer of electricity with conventional fuels, in the islands of the Aegean Sea. With this multiple role, it is facing a lot of various problems of electricity supply to the islands. These problems include but are not limited to:

- Problem of sufficiency of electricity power in almost all of the islands. This is caused mainly due to high rate of increase of demand in electric energy from time in time as a consequence of the development of those islands.
- Seasonal peak demand because of the tourist period during the summer time. The most notable point is that the peak energy demand happens in the afternoon, largely because of the extended use of air conditioning. This is when photovoltaics have their best performance.
- The age of the electricity generator units is very high, which will require the replacement of many autonomous petroleum units in the near future. It is very common for generators on the islands to have an age in excess of 40 years. These old generators are exceptionally inefficient. Many of these units have been characterized by the RAE (Regulating Authority of Energy) as "unreliable" and "problematical" in their operation.[16]
- Inefficient grid networks for distribution of the energy. Many of them need replacement as they are also over 30 to 40 years old.
- Very high environmental burden, taken that for each kilowatt/hour that is produced in the oil stations, 1 kilo of Carbon dioxide CO_2 is released in the atmosphere. The total emissions of Carbon dioxide CO_2 in the islands are roughly 4 millions tons annually. Moreover, these stations (often near built-up areas) pollute the local environments and are exceptionally noisy.

[16] Oikologos.gr, http://www.oikologos.gr/News2005/0236.html, Last Accessed: June 2007.

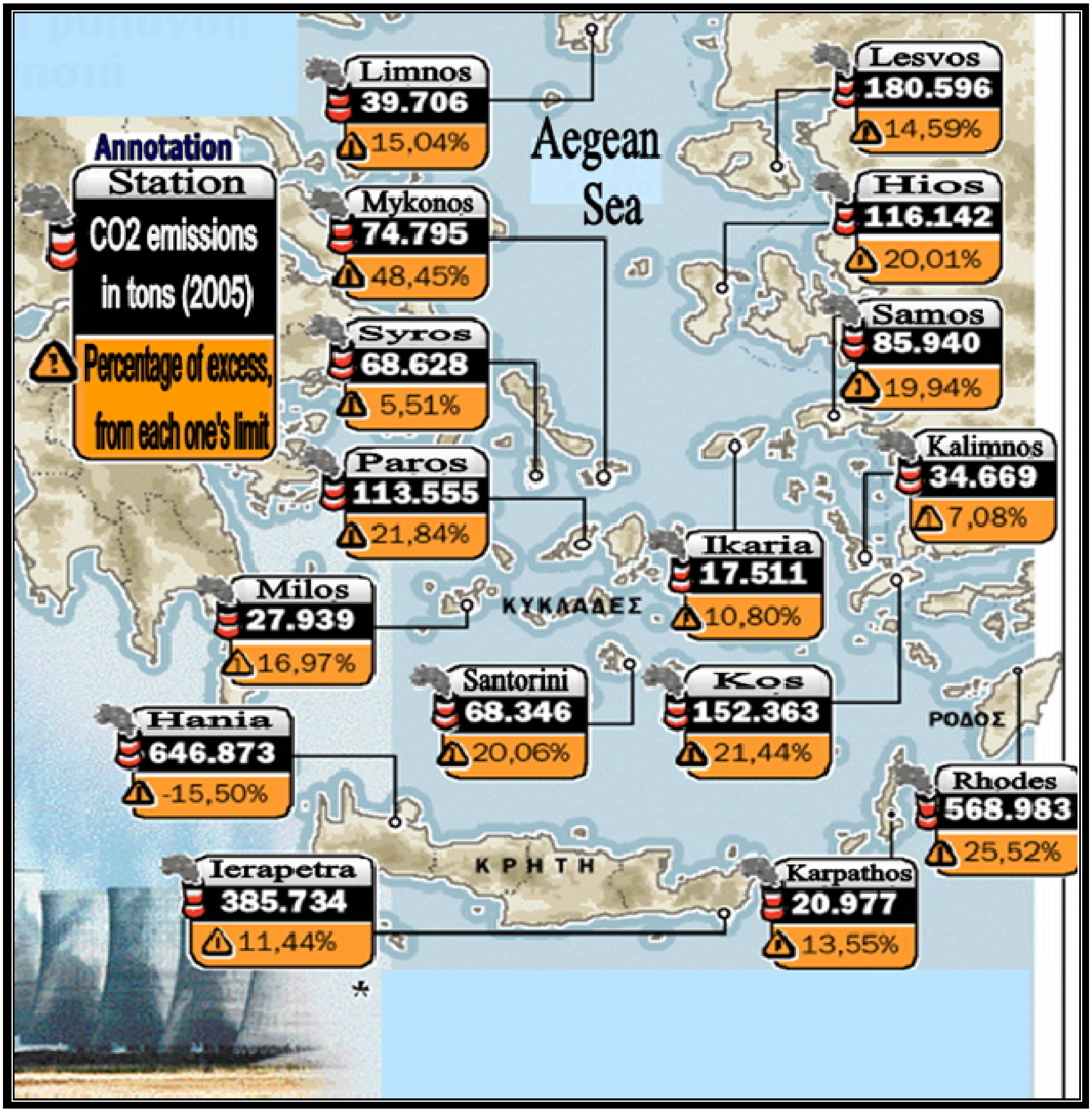

Figure 7. Percentage of Excess of CO2 emissions in the Off grid islands[17]

- Very high cost of production in the islands. The cost of electricity production for the NATIONAL ELECTRICAL COMPANY in the islands is higher than the cost of electric energy on the mainland, with the result that the other consumers of the country subsidizes the islander regions with more from 300 millions of Euros annually. The cost of fuel

[17] "Ta Nea" daily newspaper http://data.tanea.gr/D2006/D0715/1el21a.gif, Last Accessed: March 2007.

> constitutes almost 50% of the total cost of each kilowatt/hour. These fuel costs are tied to the international oil market and are very sensitive to international oil price fluctuations.

In the above costs the researchers have not calculated the “exterior” cost that the society is paying as a price for the operation of pollutant oil stations. These costs are the consequences that the combustion of oil has on the health, the environment, and the climate of planet. The relative study of the National Technical University of Athens (NTUA), on the assessment of this cost in the case of oil stations in the Greek islands (in the frame of European program ExternE 2001), reported that this `exterior' cost would be to load the price of a kilowatt/hour at 4-6.8 cents (0.04-0.068 €/KWh). If indeed the repercussions of climatic changes are proved more unfavourable as some have forecasted, these costs reach 0.2 €/KWh.

In other words, the real medium price per kilowatt/hour in the islands should be calculated at about 0.2-0.36 / KWh; however, this is higher in the periods of peak energy production, and in the very small islands (keeping in mind the recent revaluations in the prices of oil) it exceeds of more than the 1 Euro / KWh. If the fears of global climate change materialize, such as those shown by many national and International Studies like the recent study of National Observatory of Athens (February 2005), which forecasts that by the end of the century there will be an increase of medium temperature of 7-8 degrees in the region of Aegean in the month of July above the expected medium increase in world level, then there will be a concomitant need for additional energy.

In order to face these problems (mainly that of sufficiency of power), PPC is planning the installation of many new oil units to generate tens of megawatts (MW) of electricity. This choice, however, simply extends the current situation and it does not solve, in the long run, the problems of high cost generation or the environmental dimensions of production of energy.

Directive 2001/77/EU “On the promotion of electric energy that is produced by renewable sources in the internal market of electric energy” forecasts for Greece an objective of power from renewable energy sources in percentage of crude consumption of energy at year 2010 equal with 20,1% of the total energy production. Greece is the only

country in the E.U. (together with Portugal) that will not even come close to reaching this objective. This is because the Renewable Energy Sources (RES) have been stuck in incredibly bureaucratic pathways.

The PPC has not supported the use of renewable energies. Other than the big hydroelectric units in the mainland that were made in the 70s, the RES barely constitute 0,3% of the total generation of electricity of the company.

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III. LEGISLATION REGARDING THE USE OF RENEWABLE ENERGY SOURCES

A. THE NEW LAW FOR RENEWABLE ENERGY SOURCES IN GREECE AND MEASURES FOR THE DEVELOPMENT OF PHOTOVOLTAIC APPLICATIONS IN THE COUNTRY[18]

On 22 June 2006 the Hellenic Parliament approved Law 3468 referring to "Production of Electricity from Renewable Energy Sources and High Efficiency Cogeneration of Heat and Power and other Devices."

This new law introduced the European Community directive 2001/77/EC and the European council resolution of 27 September 2001 for "*the promotion of electricity generated by the Renewable Energy Sources (RES) to the internal electricity market*," into Greek legislation. Moreover, the electricity production by RES is further promoted in the internal market, giving priority to RES over conventional methods of energy production.

1. Scope and Aims

The main scope of this Law is to establish an adequate legislative and regulatory framework in order to support investments in RES and high efficiency Cogeneration of Heat and Power (CHP), and finally enhance the penetration of these resources in the energy mix of the country. According to the EC 2001/77 Directive the National Target is set to a 20.1% RES share of the total electricity production by 2010. The target for 2020 is 29%. The generation of electricity by RES and CHP is promoted over other means of production of power with specific regulations and principles.

[18] The chapter is based on the paper of C. Protogeropoulos presented in the European Photovoltaic Solar Conference September 2006.

High Efficiency CHP is defined as a cogeneration process that ensures energy savings of at least 10% compared to the process wherein the heat and electricity are produced from separate processes - Small (up to 1MWe) and Very Small (up to 50kWe) cogeneration units that achieve energy savings in this manner are included regardless of the percentage.

Another major concern of the new Law is to ensure compliance with the environmental targets of the Kyoto protocol; and to ensure that the vast RES potential of the country, especially the wind and solar, is realized. The law is also an attempt to attract large scale investments by simplifying the procedures to acquire a license for energy production.

2. Previous Experience

Renewable energy usage began officially with Law 2244 of 1994 "*Regulation of issues related with the production of electrical power from RES and conventional fuel and other provisions*," which established for the first time the legislative environment for the use of RES and gave access to the grid for individual energy producers.

Law 2244 proved to be insufficient for its intended purpose and it was amended in order to resolve technical and processing issues. Because of these amendments, and laws that were introduced during the last decade, the legislature environment became extremely complicated and bureaucratic, which actually created more of an obstacle for further development of RES in the country than support. For solar electrification in particular, PVs were treated in the same manner with the other RES. The bureaucratic processes for licensing and the lack of reasonable Feed-in tariffs caused many problems in trying to connect to the main grid. This constrained many investment initiatives for PV.

A more specific framework for RES was established with Law 2773 of 1999 by introducing the Regulatory Authority for Energy (RAE) which initiated the deregulation of the electrical energy market.

3. Energy Production License

An Energy production license is required for power production from RES. The license is provided by the Ministry of Development, after an assessment based on the following criteria:

- National security
- Protection of public health and safety
- Overall safety of the System and the Grid as well as the relevant hardware equipment
- Energy validity of the project under evaluation
- Maturity of the suggested project development procedure, based on the studies that are presented, the opinion of involved authorities, etc.
- Adequate access rights to the land to be used for the project installation
- The potential of the investor to materialize the project based on the financial and technical adequacy, and ability.
- Ensuring delivery of public benefit services and protection of the clients
- Protection of the environment according to the existing legislation

RAE receives the applications for issuing the Energy Production License (EPL) by the interested parties. During the evaluation and assessment process the RAE may collaborate technical details with the system Operator to facilitate the connection with the Grid. Wherever required by the legislation RAE must forward to the responsible authority the Preliminary Environmental Impact study which accompanies the application. PV stations of nominal capacity <=150kWp are exempted from the requirement of issuing an EPL. Additionally, autonomous power plants of installed power <=5kWe are exempted. An exemption decision by RAE is not required for grid connected RES of installed power <= 20kWe unless grid congestion on non interconnected islands occurs, or autonomous plants of power <=50kWe occurs. Practically, this means that small grid connected PV systems of power below 20kWp are excluded from the procedure to submit to RAE, or even an application for exemption, thus simplifying the licensing procedures for installers and users in the residential sector.

4. Environmental Approvals

In the new Law (3468 of 2006) specific authority is given for the installation of power plants based on RES. Photovoltaic systems below 20kWp are exempted from the environmental terms procedure. In order for a Preliminary Environmental Assessment and Evaluation (PEAE) to be initiated, an investor submits an application to the RAE, which is then forwarded to the Direction of Environment and Land Planning (DELP) of the district of the intended project installation. The application is accompanied by a Preliminary Environmental study (PEI) which includes the following:

- Location and capacity of the power plant
- Identification of the RES or other technology to be used and a general technical description of the project
- Conditions in the area of application with main focus on physical and human parameters
- Usage of natural resources
- Affiliations and synergies with other projects or activities
- Production of waste
- Pollution and causes of annoyance
- Measures for prevention of accidents due to material or technological installations
- Preliminary summary of measures meant to prevent or restrict or makeup considerable environmental impact
- Summary of the main selection criteria of the final project, bearing in mind the environmental impact.

The DELP sends the application along with the documentation to a list of various authorities, waiting for their response which should occur within 20 days after delivery. The validity of the PEAE lasts for three years.

In order for the Environmental Terms Approval (ETA) to be initiated an Environmental Impact Study (EIS) is submitted by the investor to the Director of Planning and Development (DPD) of the district of the intended project installation, which is then forwarded to the DELP for assessment. The application is accompanied by an approved PEAE and an environmental study which includes the following:

- Detailed description of the project and accompanying works, such as civil works, connection to the grid, etc.
- Description of the existing environmental conditions, including documentation for the assessment of the main environmental impact on humans, fauna, flora, soil, water, etc., as well as the interaction of these parameters.
- Assessment and evaluation of the direct and indirect affiliations and synergies concerning impact to humans and the physical environment.
- Summary of measures meant to prevent or restrict, or make up considerable environmental impact.
- Summary of the main alternative to the intended project solutions and identification of the main selection criteria of the final project bearing in mind the environmental impact.

The EIS is sent to the:

- Prefecture council of the district for installation
- Institutions for the management of protected areas

5. Installation and Operation Permits

An installation permit is required for the setting of a RES power plant. The installation permit is issued by decision of the Prefecture General Secretary in the boundaries of which the plant shall be installed. The validity of the installation permit is two years and can be extended for another two years in cases where at least 50% of the investment has been realized.

Additionally an Operation permit is required for the operation of RES and HE-CHP plants. This permit is granted by decision of the body that is responsible for issuing the installation permit as described above, after a submission of the relevant application by the investor. Issuing the Installation and Operation permits is not necessary in cases of exemption of the Energy production License as described above.

The following table presents the licenses and permits required and timetable:

Description of activity	Days required	Total days
1. Issuing of PEAE	55	55
2. Issuing of ETA	85	140
3. Consultation of the RAE to the Minister of MoD on the EPL	90	230
4. Decision of the Minister of MoD on the EPL	15	245
5. Issue of the Installation permit from the Prefecture General Secretary	15	260
6. Issue of the Installation permit from the minister of MoD (if failure in 5. above)	30	290
7. Issue of the Operation permit from the authority that granted the Installation permit	15	**305**

Table 3. Licenses and timetable.

Thus, 305 working days correspond to approximately 12 months total period.

6. Access to the Grid and Feed-in Tariffs

Provided that the safety of the Grid is not endangered, the New Law 3468 obliges the Operator to give priority to RES power plants irrespective of their installed capacity, except hydro plants of more than 15MWe. This applies in both the interconnected system and the interconnected islands. In order for RES and HE-CHP to be integrated into the system or the Grid, including the non-interconnected islands Grid, the Operator is obliged to sign an electricity sale contract with the energy production license owner. This contract is valid for 10 years and can be extended for another 10 years after a written declaration by the energy producer. Remuneration of the energy products is based on a feed-in Tariff system, which is presented in the following table:

	Feed-in Tariff, (euro/Mwh)	
Power supply source	Interconnected system	Non-interconnected islands
Wind	73.0	84.6
Wind off shore	90.0	90.0
Small Hydro<15MWp	73.0	84.6
PV Solar <100 kWp	450.0	500.0
PV Solar >=100kWp	400.0	450.0
Other Solar<5MWe	250.0	270.0
Other Solar>=5MWe	230.0	250.0
Geothermal, Biomass	73.0	84.6
Other RES	73.0	84.6
HE-CHP	73.0	84.6

Table 4. Feed-in Tariffs Remuneration.

Pricing for the electricity produced is done on a monthly basis except in the case of power stations connected to the Grid, where pricing takes place every four months. For self producers, the tariffs presented in table 4 are valid for a maximum power capacity of 35 MW for the surplus energy fed into the grid, with an upper limit of 20% of the total energy produced by the plant on an annual basis.

7. Photovoltaic Stations

As seen in Table 4 above, pricing of the energy produced by PV is adequate for sustainable market development in the country. The Law 3468 is meant to promote electricity production from PV, and apart from tariffs this will be implemented through the so-called Photovoltaic Plant Development Program to be drawn up by RAE with the approval of the minister of the Ministry of Development (MoD). The main targets of the PV program refer to the development of plants of total power at least 500 MWp grid connected stations and at least 200 MWp stations integrated to the non-interconnected islands grid.

8. Coordination and Promotion Mechanisms

Committee for the Promotion of RES and HE-CHP

- For large scale investments the MoD establishes a committee for the promotion of RES and HE-CHP large scale investments in the country. The Committee's main task is to promote investments regarding electricity production of RES of installed power of more than 30 MWe, or a total budget of more than 30 MEuros, and to resolve efficiently any matters arising during the Licensing, Installation and Operation permissions procedure.
- For small scale investments, the MoD establishes a committee for the promotion of RES and HE-CHP investments in the country. The Committee's secondary task is to promote investments regarding electricity production of RES of installed power less than 30 MWe or total budget less than 30 MEuros and to resolve efficiently any matters arising during the licensing and installation and Operation permissions procedure.

9. Specific Charge

After a RES plan is established, electricity producers who hold an Energy Production License are obliged to pay a Specific Charge of 3% of the electricity sales to the system Operator before application of the Value Added Tax (VAT). Electricity producers from PV plants are exempted from this specific charge.

10. Present Market Reactions and Comments

The public reaction to this new law was instantaneously positive, showing that the new measures for the promotion of PV technology and the solar electrification of Greece are widely supported. For now the total installed power is around 40.6MWp with the largest project being 9MWp and the smallest 410kWp. Additionally, a new factory for the production of crystalline PV has been built. As for the household sector (PV systems of capacity below 20kWa market reaction has not yet been recorded. As explained in the new Law such systems are exempt from the obligation to obtain an Energy Production License, as well as the total procedure for the Environmental Terms Approval. On the other hand, owners of small PV systems are obliged to inform the RAE and MoD on PV

installations in order that those systems can be registered. The crucial factor for an adequate development of the household electrical market in Greece is the practical payment of the Feed-in Tariffs.

If an EPL is issued to an independent producer, which means that all power is fed into the grid, then the tariffs are adequate to support development of the PV market. However, PV generators that produce electricity for themselves but make the excess power available to the grid may receive the tariffs only for the excess power sold to the grid.

11. Conclusion

For PV applications a generous Feed-in Tariff system has been introduced and a considerable market expansion has been noticed for medium and large scale PV plants. There is some remarkable industrial activity on the way for the production of crystalline solar cells and modules. Also, specific targets have been set for PV applications in the PV plant development program with minimum capacities of 500MWp grid connected and 200MWp on non-interconnected islands to be installed by 2020. Greece is showing that it intends to turn to renewable energy to satisfy its future energy needs.

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IV. LCCA AND CBA ANALYSIS

A. GENERAL

In this chapter, a life cycle cost analysis will be examined. And a cost benefit analysis of the two different hypothetical power supply options for the Greek islands. One option is the existing powering method that uses fueled generators and the alternative option is photovoltaic panels with the Atira technology embedded. This analysis is essential before we get into any numbers in the next chapter.

It should be noted that the modern Greek governments understands the power problem in the Aegean, however they have only recently examined the possible alternative solutions seriously. In the various meetings that have made between all the corresponding commissions the option of using photovoltaics has been repeatedly rejected as non beneficial mainly due to large, up front costs. Instead, other options have been approved. One such decision is related to the islands closer to the prefecture that includes some of the big Cyclades, in lieu of using a renewable energy source, the Government decided it was less costly to extend utility power links from the mainland to the islands by using underwater cable. This project has been accepted and will probably begin after 2008.

However, it does not change the dependence of Greece in the polluting lignite and the other conventional fuels. Moreover, it is also very costly because the distance between the Lavrio Port near Athens and the central terminal station in the island of Syros is 90 km. Finally, this solution wherever applied (like between Rhodes and Halki in the Dodecanese complex), has been shown to have many failures basically because of the thousands of fish boats that are traveling and fishing with drag-nets all around the Archipelago.

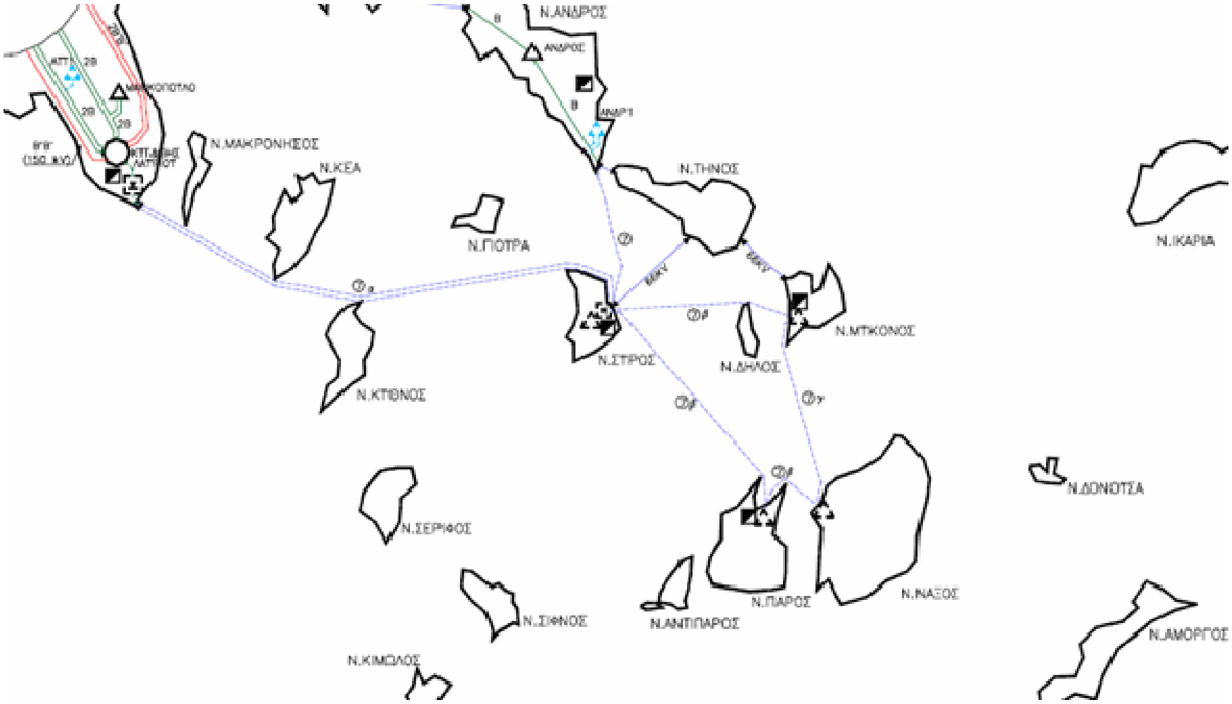

Figure 8. The prospective underwater cable for powering the North Cyclades[19]

The primary costs of the two options will be different as will the costs of operation, maintenance, and repair or replacement. A LCCA can help compare these power supply options. The LCCA consists of finding the present worth of any expense expected to occur over the reasonable life of the system. To be included in the LCCA, any item must be assigned a cost, even though there are considerations to which a monetary value may be difficult to ascertain. For instance, the cost of a liter of diesel fuel may be known; the cost of storing the fuel at the site may be estimated with reasonable confidence; but, the cost of pollution caused by the generator may require a well educated guess. Also, the competing power systems will differ in performance and reliability. To obtain a good comparison, the reliability and performance must be the same. This can be done by upgrading the design of the least reliable system to match the power availability of the best. In some cases, you may have to include the cost of redundant components to

[19] Hellenic Transmission System Operator S.A., http://www.desmie.gr/up/files/ΧΑΡΤΗΣ_ΜΑΣΜ_2006.pdf, Last Accessed: March 2007.

make the reliability of the two systems equal. For instance, if it takes one month to completely rebuild a diesel generator, you should include the cost of a replacement unit in the LCCA calculation.

B. LCCA COMPUTATION

The life-cycle cost of an electricity powering project can be calculated using the general formula:

$$\mathbf{LCCA = C + M + E + R - S}$$

where:

- The capital cost (C) of a project includes the initial capital expense for equipment, the system design, engineering, and installation. This cost is always considered as a single payment occurring in the initial year of the project, regardless of how the project is financed.
- Maintenance (M) is the sum of all yearly scheduled operation and maintenance (O&M) costs. Fuel or equipment replacement costs are not included. O&M costs include such items as an operator's salary, inspections, insurance, property tax, and all scheduled maintenance.
- The energy cost (E) of a system is the sum of the yearly fuel cost. Energy cost is calculated separately from operation and maintenance costs, so that differential fuel inflation rates may be used. Although the diesel fuel cost for running the generators is getting higher each year, the energy cost for a photovoltaic project equals zero because the sun's energy is assumed to be free of charge.
- Replacement cost (R) is the sum of all repair and equipment replacement cost estimated over the life of the system. A battery replacement is a good example of such a cost that may occur once or twice during the life of a PV system. Similarly, the replacement of a generator is assumed to be done about every 100,000 hours or 10 years of continuous operation with the optimum maintenance conditions. This simply means that in the entire twenty year life of a photovoltaic project, they are going to use at least two generators. Normally, these costs occur in specific years and the entire cost is included in those years.
- The salvage value (S) of a system is its net worth in the final year of the life-cycle period. It is common practice to assign a salvage value of 20 percent of original cost for mechanical equipment that can be moved. This rate can be modified depending on other factors such as obsolescence and condition of equipment.

Future costs must be discounted because of the time value of money. One dollar received today is worth more than the promise of $1 next year, because the $1 today can be invested and earn interest. Future sums of money must also be discounted because of the inherent risk of future events not occurring as planned. Several factors should be considered when the period for an LCCA analysis is chosen. First is the life span of the equipment. PV modules should operate for 20 years or more without failure. To analyze a PV system over a 5-year period would not give due credit to its durability and reliability. A twenty year period is the normal period chosen to evaluate PV projects. As said, this analysis will use a twenty year life span

C. COST BENEFIT ANALYSIS

A Cost-Benefit Analysis (CBA) is an estimation of the equivalent money value of the benefits and costs to a company or to a community of projects, to establish whether they are worthwhile. These projects can be new products, new processes or services and even big programs like social security systems.

Although the idea of this economic accounting was first developed by Jules Dupuit, a French engineer, in 1848, it was the British economist, Alfred Marshall, who formulated some of the formal concepts that are the foundation of CBA.

However, the practical development of CBA came as a result of the impetus provided by the U. S. Federal Navigation Act of 1936. This act required that the U.S. Army Corps of Engineers carry out projects for the improvement of the waterway system when the total benefits of the project to whomsoever they accrue, exceeded the costs of that project. Thus, the U.S. Army Corps of Engineers had to create systematic methods for measuring such benefits and costs. Yet, the Corps of Engineers did this without much, if any, assistance from the economics profession. Twenty years later in the 1950s, economists tried to provide a precise and reliable set of methods for measuring benefits and costs and deciding whether a project is worthwhile. Today, a few technical concerns of CBA have not been wholly resolved but the fundamentals are well established.

The biggest problem of a CBA is the computation of many components of benefits and costs that are not naturally obvious and that intuition fails to suggest any methods of measurement. Therefore some basic principles have to be set as a guide.

1. Common Unit of Measurement

In order to reach a conclusion as to the attractiveness of a project, all aspects of the project, positive and negative, must be expressed in terms of a common unit. The most convenient common unit is money.

This means that all benefits and costs of a project should be measured in terms of their equivalent money value. A system may provide benefits which are not directly expressed in terms of dollars but there is some amount of money the recipients of the benefits would consider just as good as the project's benefits. On the other hand and specifically in our case, the Diesel generators working all day in the Aegean islands provide a very big but difficult to estimate cost to the environment. In 2001, a very big project called Externe, by the European Union and many European organizations and universities tried to estimate these externalities and those costs to the environment.

However, not only the benefits and the costs of a project have to be expressed in terms of equivalent money value, but they also have to be expressed in terms of dollars of a particular time. This is not just due to the differences in the value of dollars at different times because of inflation. A dollar available five years from now is not as good as a dollar available now. This happens because a dollar available now can be invested and earn interest for five years and would be worth more than a dollar in five years. If the interest rate is r then a dollar invested for t years will grow to be $(1+r)^t$.

Therefore the amount of money that would have to be deposited now so that it would grow to be one dollar t years in the future is $(1+r)^{-t}$.

This is called the discounted value or present value of a dollar available t years in the future. When the dollar value of benefits at some time in the future is multiplied by the discounted value of one dollar at that time in the future the result is discounted present value of that benefit of the project. The same thing applies to costs. The net

benefit of the projects is just the sum of the present value of the benefits less the present value of the costs. Another key issue is the choice of the appropriate interest rate to use for the discounting procedure. This discount rate is determined by the formula: $d = i/i+1$ where d is the discount rate and i, is the current loan rate.[20]

2. CBA Should Represent People's Valuations as Revealed by their Actual Behavior

The valuation of benefits and costs should reflect preferences revealed by choices which have been made. In our case for example, the valuation of the benefit of cleaner air from the use of photovoltaics, could be established by finding how much less people paid for housing in the more polluted areas which otherwise was identical in characteristics and location to housing in less polluted areas. Generally the value of cleaner air to people as revealed by the hard market choices seems to be less than their rhetorical valuation of clean air.

3. Benefits Are Measured by Market Preferences

When consumers make purchases, they reveal that the things they buy are at least as beneficial to them as the money they spent. Consumers will increase their consumption of any commodity up to the point where the benefit of an additional unit (marginal benefit) is equal to the marginal cost to them of that unit, the market price.

4. Some Calculation of Benefits Require the Valuation of Human Life

Sometimes it is necessary in a CBA to evaluate the benefit of saving human lives which in our case represents the lives that are going to be saved from the closure of the diesel power stations. There is considerable antipathy in the general public to the idea of placing a dollar value on human life. Economists recognize that it is impossible to fund every project which promises to save a human life and that some rational basis is needed to select which projects are approved and which are turned down.

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[20] Wikipedia, www.wikipedia.org/wiki/Discount_rate, Last Accessed: April 2007.

The controversy is defused when it is recognized that the benefit of such projects is in reducing the risk of death. There are many cases in which people voluntarily accept increased risks in return for higher pay, such as in the oil fields, mining, or for time savings in higher speed in automobile travel. These choices can be used to estimate the personal cost people place on increased risk and thus the value to them of reduced risk. This computation is equivalent to placing an economic value on the expected number of lives saved.

5. The CBA of a Project Should Involve a with Versus a Without Comparison

The impact of a project is the difference between what the situation in the study area would be with and without the project. When a project is being evaluated the analysis must estimate not only what the situation would be with the project but also what it would be without the project. In the Aegean case for example, in determining the impact of the implementation of photovoltaics in the islands, someone must examine first the current situation without them. In other words, the alternative to the project must be explicitly specified and considered in the evaluation of the project.

6. CBA Involves a Particular Study Area

The impacts of a project are defined for a particular study area, be it a city, region, state, nation or the world. Photovoltaics, for example, have different performance in different areas. In our analysis we will concentrate in the Aegean islands of Greece.

The nature of the study area is usually specified by the organization sponsoring the analysis. Many effects of a project may “net out” over one study area but not over a smaller one. The specification of the study area may be arbitrary but it may significantly affect the conclusions of the analysis.

7. Double Counting of Benefits or Costs Should Be Avoided

Sometimes an impact of a project can be measured in two or more ways. For example, when an improved highway reduces travel time and the risk of injury the value

of property in areas served by the highway will be enhanced. The increase in property values due to the project is a very good way, at least in principle, to measure the benefits of a project. But if the increased property values are included then it is unnecessary to include the value of the time and lives saved by the improvement in the highway. The property value went up because of the benefits of the time saving and the reduced risks. To include both the increase in property values and the time saving and risk reduction would involve double counting.

8. Decision Criteria for Projects

If the discounted present value of the benefits exceeds the discounted present value of the costs then the project is worthwhile. This is equivalent to the condition that the net benefit must be positive. Another equivalent condition is that the ratio of the present value of the benefits to the present value of the costs must be greater than one.

If there are more than one mutually exclusive project that have positive net present value then there has to be further analysis. From the set of mutually exclusive projects the one that should be selected is the one with the highest net present value.

V. COST BENEFIT ANALYSIS

The broad purpose of Cost Benefit Analysis (CBA) is to help social decision making.[21] More specifically it facilitates the allocation of limited resources. Regarding government intervention one must be able to demonstrate the superior efficiency of a particular intervention relative to the alternatives, including the status quo. For this purpose we use CBA. Ex ante CBA which is the standard CBA is used in the case about whether scarce social resources should be allocated by government to a specific policy, whether program, project or regulation. However, it is generally used in the selection of a specific project.

A. METHODOLOGY

The steps of CBA are:[22] (1) specify the set of alternative projects (2) decide whose benefits and costs count, (3) catalogue the impacts and select measurement indicators, (4) predict the impacts quantitatively over the life of the project, (5) monetize (attach dollar values) to all impacts (6) discount benefits and costs to obtain present values (7) compute the net present value of each alternative, (8) make a recommendation based upon the net present value.

All the alternatives analyzed are referencing to the current demand of Amorgos Island, of 2.9MW.[23] Several assumptions are made with regard to the three alternatives specified in the "Identify Set of Alternatives Projects" section. First due to lack of data concerning the existing diesel-generators on the island and their relevant operation and maintenance (O&M) costs, we assumed that the current demand of 2.9MW could be

[21] Boardman Anthony et al., Cost-Benefit Analysis: Concepts and Practice, Second Edition. New Jersey: Prentice Hall, 2001, p. 2.

[22] Ibid, p. 7.

[23] Personal communication on February 15, 2007.

satisfied with five Caterpillar generators of 750Kw (one generator as a reserve). The O&M costs are counted per KW and they are taken from a consulting report for the State of California.[24]

Second, we assumed that in the second scenario additional charges in the form of a fee will be paid by the Greek government as there will not be any excess carbon dioxide emissions with the concurrent use of diesel generators and photovoltaics.

Third, the operation and maintenance costs for the diesel generators in the second scenario are cut by a percentage equal to the penetration capacity of the PV installation, because of the contribution of the photovoltaics in the overall capacity of the system especially for the minimization of the cold starts of the generators. The size of the photovoltaic plant installed in the second scenario is equal to the percentage of the emission exceeded for the specific island, so an installation of 725Kw or twenty five per cent Penetration capacity is introduced (Penetration capacity is the ratio of the installed capacity to the existing one). The installation is introduced to eliminate the environmental impact of the CO2 emissions.

Fourth, these environmental fees are considered as a cost in the first scenario.

Fifth, the O&M costs for the diesel back up generator in the third scenario are considered at 25% of those in the first scenario.

Sixth, the existence of two energy sources provides a sense of reliability to the final user. This, in terms of reliability, is valued in the same way as in the case where we have only electricity from the main Grid, which is considered more reliable by the consumers in Greece. We consider the value based on frequency, duration and timing of utility service interruptions which determine a direct cost inconvenience and discomfort. We take into consideration the Residential value of service. This has a qualitative impact which is going to be discussed in the recommendations area.

Seventh, we consider the salvage value of the used equipment in all the solutions to be equal to the twenty per cent of the initial purchase value.

[24] Navigant Consultant report prepared for: California Energy Commission, July 9, 2004.

Eighth, we assume the PV installation batteries cost to be twenty per cent of the total cost of the panels. Batteries will be incorporated only for the third scenario of stand alone PV systems. Batteries should be replaced every five years so the capital cost for their acquisition will be incorporated to the Net Present value Analysis.

Ninth, the life cycle of the Generators is considered to be ten years so the capital costs for their replacement will be taken into account in the Net Present value calculations.

The present cash flow streams are projected over a period of twenty years and the net present value criterion is selected for the evaluation of the projects.

B. IDENTIFY SET OF ALTERNATIVE PROJECTS

Step 1 of CBA requires the analyst to specify the set of alternative projects.[25] There are three alternatives analyzed which will be presented in this CBA.

- The first alternative involves the installation of five Caterpillar diesel generators on the island producing energy in the more traditional way by using fossil fuel. The generators are expected to exceed the emission limits set by the Kyoto protocol and a corresponding fee is paid by the Greek government. The generators are required to satisfy the peak demand of 2.9 MW. The island is not connected to the main grid.
- The second alternative involves an additional installation of photovoltaics with a capacity of 725kw on the island, this option ensures the production and delivery of electricity and to reduces the amount of carbon dioxide emitted in the atmosphere. The costs of existing generators are also captured in this option/ analysis.
- The third option provides peak demand via by a photovoltaic installation of 2.9 MW with back up generators of 2.9 MW. The O&M and duel costs of the back up generator are assumed to be 25% of the first option since the back up generator will be used in an emergency situation.

[25] Boardman Anthony et al., Cost-Benefit Analysis: Concepts and Practice, Second Edition. New Jersey: Prentice Hall, 2001, p. 7.

C. DECIDE WHOSE BENEFITS AND COSTS COUNT

Step 2 of a CBA requires the analyst to decide who has standing and whose benefits and costs should be counted.[26] A stakeholder analysis is an effective tool to accomplish this task. By doing this we see the relationships needed for the success of a participatory change initiative or policy. The analysis should center on which alternative of the CBA the stakeholder has the ability to influence. The analysis will at a minimum identify and define the characteristics of key stakeholders and assess their capacity to participate in the decision. The following table provides a summary of key stakeholders and their potential to influence the choice of alternatives analyzed in the CBA

Stakeholder	Influence on the Alternatives
Island Residents	Medium
Ministry of Development	High
European Union	Medium
Public Power Corporation	High
Private Contractors/ Entrepreneurs	High

Table 5. Stakeholder Analysis.

The residents of the island generally are in favor to the connection of their system to the main grid. They generally feel more secure with this option because they regard it a stable and reliable source of electricity. Little faith has been placed on Distributed Generation solutions such as diesel generators and renewable energy sources. Between the two solutions they prefer the first one due to the wide perception which is still prevalent in Greece that the traditional sources of energy are more reliable. Those traditional sources of energy simply enhance their sense of security. Their potential to influence the decision is assigned a medium or at least not as high as expected because of their relative small number and correspondingly low potential to influence constituency elections.

[26] Boardman Anthony et al., Cost-Benefit Analysis: Concepts and Practice, Second Edition. New Jersey: Prentice Hall, 2001, p. 7.

Generally, the Ministry of Development provides entrepreneurs incentives to invest in renewable energy sources and has issued directives which favor the electricity producers from RES. The MoD is very influential and has the ability to finance various projects. However, the leadership of the MoD are elected political officials and are subject to pressure by interest groups, that may not wish to expand the use RES.

The European Union with its respective committees influences the legislature at a macro level and the approval and financing of specific projects at the micro level. Despite the fact that its Directives have forced the member states to assimilate them into national laws especially the percentage of energy produced by RES, the EU does not have a strong say in special cases like that of the off-grid Greek islands. Although it provides incentives in the form of subsidies to the national Mod it does not exert influence on specific project decisions.

The Public Power Corporation is probably the main stakeholder. The Organization is generally not in favor, of RES expansion even in the cases of the off-grid islands. Despite the fact that connection to the main grid is costly and unreliable, the 4 PPC has not adopted the use of RES. This may be due to the influence of traditional energy; interest groups. Moreover, the worker unions within the Corporation, driven by the fear of losing their jobs, make continuous attempts to maintain the status quo in the energy sector in Greece. All the large scale proposals are relied upon the use of hydro power or fossil fuel such as lignite and diesel.

The Private contractors/Entrepreneurs have significant influence here but they appear split in their preferences. Because of the potential of RES and the financing incentives given by the EU and MoD they started having a more positive attitude toward new RES solutions. Many of them who did not expand their businesses to RES still influence the MoD and the Public Power Corporation in the promotion of fossil fuel projects. Their potential to influence a decision is high.

D. CATALOG IMPACTS AND SELECT MEASUREMENT INDICATORS

Step 3 of a CBA requires the analyst to list the physical impacts of the alternatives as benefits or costs and to specify the impacts' measurement units.[27] Impacts and measurement indicators for the three alternatives analyzed for this CBA are summarized in the following table:

Impacts and measurement Indicators	**Diesel Generators**	**Diesel generator and Photovoltaics**	**Photovoltaics and Back up Generator**	**Units of measurement**
Costs				
Fuel	Fuel costs obtained from Navigant Consulting Report[28]	Fuel costs obtained from Navigant Consulting Report	Fuel costs obtained from Navigant Consulting Report	Euros
Initial Capital costs	Costs obtained from Navigant Consulting Report[29]	Costs obtained from the market and Nav. Consult. Report	Costs obtained from the market and Nav. Consult. Report	Euros
Maintenance Costs	Maintenance Costs obtained from Navigant Consulting Report[30]	Maintenance Costs obtained from Navigant Consulting Report	Maintenance Costs obtained from Navigant Consulting Report	Euros
Environmental Costs	Environmental Costs obtained from MoD[31]	Environmental Costs obtained from MoD	Environmental Costs obtained from MoD	Euros
Benefits				
Reliability and Power Quality	No additional reliability to the system	Additional reliability from the existence of two sources of energy Value of service estimates from the Navigant Consulting Report	Additional reliability from the existence of two sources of energy Value of service estimates from the Navigant Consulting Report	Qualitative impact

Table 6. Impacts and Measurements Indicators.

27 Boardman Anthony et al., Cost-Benefit Analysis: Concepts and Practice, Second Edition. New Jersey: Prentice Hall, 2001, p. 8.

28 Navigant Consultant report prepared for: California Energy Commission, July 9, 2004, p. 114.

29 Ibid., p. 107.

30 Ibid., pp. 117, 118.

31 Personal communication on February 20, 2007 and http://www.physics4u.gr/articles/2005/marketpollution.html, Last Accessed: March 2007.

E. PREDICT IMPACT QUANTITATIVELY OVER LIFE OF PROJECT

Step 4 of a CBA is to quantify impacts that can be reasonably quantified for each alternative over the life of the project.[32] The Fuel, Initial Capital, Maintenance, Environmental costs, are measured in dollars and their impact will be discussed in the monetized impacts section.

F. MONETIZED IMPACTS

The fifth step of a CBA is to monetize each of the impacts identified in step 3[33]. The impacts to be monetized are fuel costs, initial capital costs, maintenance costs and environmental costs.

1. Fuel Costs

The fuel costs are calculated based on the data derived from the Navigant report for the state of California. The prices are converted to euros using an exchange rate of 1.29.

For the first scenario it is assumed that a number of generators required, remain ideally in operation for 24 hours for 365 days a year and that the total kWh produced is 25,404,000. With a total cost of 0.046 euros of diesel per kWh[34] the total cost for diesel per year is **1,168,584** euros.

For the second scenario we assume that the total operation time falls by an amount equal to the penetration capacity of the photovoltaic installation which means by roughly 25%. Accordingly the total fuel costs will account for 75% of that of the first scenario, this equates to a total fuel cost of **876,438** euros.

For the third scenario we assume that the total operational days per year for the back up generators will be 91.25 days. 25% of the days will not be sunny. If we further

[32] Boardman Anthony et al., Cost-Benefit Analysis: Concepts and Practice, Second Edition. New Jersey: Prentice Hall, 2001, p. 9.

[33] Ibid., p. 10.

[34] Navigant Consultant report prepared for: California Energy Commission, July 9, 2004, p. 114.

assume a constant operation of the back up generators throughout these days then we have a total of 6,351,000kw with a fuel consumption cost of **292,146** euros.

2. Initial Capital Costs

a. Generator Costs

For the diesel generators the Initial capital costs are equal to 390.625/Kw, as defined in the Navigant Report.[35]

In the first case we have five generators with a total capacity of 3750kw which equates to a total cost of **1,464,843.75** euros. Additional capital costs for the renewal of the generators at the end of their life cycle will be the same amount of money. The generator replacement will take place in year ten. Salvage value for the replacement of the existing generators is also taken into account in year ten as a positive cash flow. Salvage value is projected to be **292,968.75** euros, which is twenty per cent of the initial capital cost

In the second case we consider the initial capital costs as the same with those of first case, because we accept the status quo as is and by only adding the photovoltaic installation to minimize the carbon dioxide emissions.

In the third case the total cost of the back up generator will be **1,132,812.5** euros. There is no additional generator in this option to serve as a back up one. The life-cycle of the generators in this case is considered to be the same with the life cycle of the PV system. This is because they will operate only in emergency situations, which results in a expansion of their life-cycle.

b. Cost of the PV Installation, Second Alternative

We divide the actual power load with the average low peak sun hours[36] and we have the result of 725,000/3.5=207,142.85 W.

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[35] Navigant Consultant report prepared for: California Energy Commission, July 9, 2004, p. 107.

[36] The methodology of the calculations is taken from the MBA Professional Report: Operation Solar Eagle by C. Austin, R. Borja and J. Philips, Naval Postgraduate School.

The solar panel to be used is a Sharp 175 with nominal capacity of 175 W/m^2. We multiply the nominal capacity by 0.8 for a 80% efficiency and we have 175*0.8=140 W.

We divide the outcome of step 2 by the actual capacity of the panel from step 3 and we have the total number of panels to be installed 207142.85/140=1478 panels.

Unit cost for the panel is 643.8 euros.[37] We multiply the cost per unit with the number of units and we have the total cost of the panels 1478*643.8=**952,561.22** euros.

Using 10 Kw inverters for the power load of 85,714.2W we have a total number of inverters 21. Unit cost of a 10 KW inverter is 5600[38] euros so the total inverter cost is **117600** euros. The prices below are taken from suppliers and the market in Greece.[39]

Installation costs: **10,000**

Structure costs: **10,000**

Data controller: **500**

Consulting services: **3,000**

Civil works: **5,000**

Total costs: ***1,098,661.22***

c. Cost of the PV Installation, Third Alternative

The calculation of the installation costs for the PV in the third case is described in detail in the Appendix: "Business plan for Amorgos Island," and they are equal to 4,303,544.9 euros, plus the batteries cost: **4,523,277.12** euros.

Salvage value is equal to twenty per cent of the initial capital cost for all the PV systems at the end of their useful life.

[37] Personal communication on 15 February 2007 with Prosolar Greek Representative.

[38] Ibid.

[39] Ibid.

3. Operation and Maintenance Costs

a. Diesel Generators

For the diesel generators the total O&M costs are taken from the Navigant Report and they are 1.95[40] cents of Euro/kWh.

In our first case we have a total kWh of 25,404,000. Multiplied by the cost of kWh for a total O&M costs of **495,378** euros per year.

In the second case we assume a reduction of the O&M costs equal to the Penetration capacity of the PV installation, so the total amount of costs will be 75% of the first case, therefore, **371,533.5** euros.

In the third case the total O&M costs will be 25% of the first solution, as described in our assumptions, so it will be **123,844.5** euros.

b. Photovoltaic Systems

We consider the O&M costs for the PV systems 2.34 euros per Kw/ year.[41]

According to this rate and the total electricity production by PV for each scenario we have the following results:

In the **second scenario** we have a total of O&M costs of **1696.5** euros.

In the **third scenario** we have a total of O&M costs of **6786** euros.

4. Environmental Costs

It is a fact that Greece violates the carbon dioxide limit by 2.7 million tons per year. From 2008 the fee for this violation will reach up to a 100 euros per tone of CO_2. Assuming that in a typical island like Amorgos, which is the size of Santorini Island, we have a 25% violation of carbon dioxide permits, this is equivalent to 11,391 excessive

[40] Navigant Consultant report prepared for: California Energy Commission, July 9, 2004, p. 117.

[41] Ibid., p. 107.

CO_2 tones per year which results in an annual total fee of 1,139,100 euros. For the purpose of our analysis it is assumed that the Company buys the pollution permits for 10 euros per ton. This equates to an environmental cost of **111,391** euros **for the first scenario**.

In the second case there are no environmental costs because there is no pollution since the PV installation eliminates any violations of the Kyoto Protocol.

In the third case there is also no excessive pollution because the diesel generator operates only as a back up source of energy.

G. DISCOUNTING BENEFITS AND COSTS TO OBTAIN PRESENT VALUES

Step six of the CBA requires the analyst to discount all benefits and costs to obtain present values of the three alternatives analyzed.[42] The discount rate is calculated according to the current loan rate *i* offered by the Greek banks which is 6.5% the discount rate is calculated by the formula:

$$d= i/i+1=6.5\%/1+6.5\%=0.061 \text{ or } \mathbf{6.1\%.}$$ [43]

No Provision is made in this study to account fro inflation. All computations were completed using Microsoft Office Excel. When calculating NPV 20 years were analyzed for this project because we estimated the useful life of the generators up to twenty years.

The costs of following the first solution of two diesel generators are displayed in the following table (NPV at the end of year):

[42] Boardman Anthony et al., Cost-Benefit Analysis: Concepts and Practice, Second Edition. New Jersey: Prentice Hall, 2001, p. 10.

[43] Wikipedia, www.wikipedia.org/wiki/Discount_rate, Last Accessed: April 2007.

Alternative one

Year	Fuel Costs	Operation and maintenance costs	Environmental costs	Yearly total
1	-1,168,584	-495,378	-111,391	-1,775,353
2	-1,168,584	-495,378	-111,391	-1,775,353
3	-1,168,584	-495,378	-111,391	-1,775,353
4	-1,168,584	-495,378	-111,391	-1,775,353
5	-1,168,584	-495,378	-111,391	-1,775,353
6	-1,168,584	-495,378	-111,391	-1,775,353
7	-1,168,584	-495,378	-111,391	-1,775,353
8	-1,168,584	-495,378	-111,391	-1,775,353
9	-1,168,584	-495,378	-111,391	-1,775,353
10	-1,168,584	-495,378	-111,391	-2,947,228[44]
11	-1,168,584	-495,378	-111,391	-1,775,353
12	-1,168,584	-495,378	-111,391	-1,775,353
13	-1,168,584	-495,378	-111,391	-1,775,353
14	-1,168,584	-495,378	-111,391	-1,775,353
15	-1,168,584	-495,378	-111,391	-1,775,353
16	-1,168,584	-495,378	-111,391	-1,775,353
17	-1,168,584	-495,378	-111,391	-1,775,353
18	-1,168,584	-495,378	-111,391	-1,775,353
19	-1,168,584	-495,378	-111,391	-1,775,353
20	-1,168,584	-495,378	-111,391	-1,482,384[45]
CUM TOTAL	-23,371,680	-9,907,560	-2,227,820	-35,507,060
			Initial capital costs Gen	**-1,464,843.75**
			NPV @ 6.1%=	**-22,222,304.02**

Table 7. Net Present Value of the First Alternative.

The costs of following the second solution of introducing a PV installation with a penetration capacity equal to that of the percentage of violation in carbon dioxide emissions are displayed in the following table (NPV at the end of year):

[44] The replacement cost for the generators and their salvage value is incorporated in this cell.

[45] Salvage value for the generators is incorporated in this cell.

Alternative two				
Year	**Fuel costs**	**Operation and maintenance costs PV**	**Operation and maintenance costs Gen**	**Yearly total**
1	-876,438	-1696.5	-371,533.50	-1,249,668
2	-876,438	-1696.5	-371,533.50	-1,249,668
3	-876,438	-1696.5	-371,533.50	-1,249,668
4	-876,438	-1696.5	-371,533.50	-1,249,668
5	-876,438	-1696.5	-371,533.50	-1,249,668
6	-876,438	-1696.5	-371,533.50	-1,249,668
7	-876,438	-1696.5	-371,533.50	-1,469,400[46]
8	-876,438	-1696.5	-371,533.50	-1,249,668
9	-876,438	-1696.5	-371,533.50	-1,249,668
10	-876,438	-1696.5	-371,533.50	-2,421,543[47]
11	-876,438	-1696.5	-371,533.50	-1,249,668
12	-876,438	-1696.5	-371,533.50	-1,249,668
13	-876,438	-1696.5	-371,533.50	-1,249,668
14	-876,438	-1696.5	-371,533.50	-1,469,400[48]
15	-876,438	-1696.5	-371,533.50	-1,249,668
16	-876,438	-1696.5	-371,533.50	-1,249,668
17	-876,438	-1696.5	-371,533.50	-1,249,668
18	-876,438	-1696.5	-371,533.50	-1,249,668
19	-876,438	-1696.5	-371,533.50	-1,249,668
20	-876,438	-1696.5	-371,533.50	-736,967[49]
CUM TOTAL	-17,528,760	-33930	-7,430,670	-24,993,360
			Initial capital costs Gen	**-1,464,843.75**
			Initial capital costs PV+batteries	**-1,318,393.44**
			NPV @ 6.1%=	**-17,733,629.37**

Table 8. Net Present Value of the Second Alternative.

The costs of using a big PV installation in order to satisfy the demand of the island with the use of diesel generator only as a back up system are displayed in the following table (NPV at the end of year):

46 Cost of new batteries incorporated.

47 Cost of new generators and salvage value from old ones incorporated.

48 Cost of new batteries incorporated.

49 Salvage value of both generators and PV systems incorporated.

Alternative three

Year	Fuel costs	Operation and maintenance costs PV	Operation and maintenance costs Gen	Yearly total
1	-292,146	-6,786	-123,844.50	-422,777
2	-292,146	-6,786	-123,844.50	-422,777
3	-292,146	-6,786	-123,844.50	-422,777
4	-292,146	-6,786	-123,844.50	-422,777
5	-292,146	-6,786	-123,844.50	-422,777
6	-292,146	-6,786	-123,844.50	-422,777
7	-292,146	-6,786	-123,844.50	-642,509[50]
8	-292,146	-6,786	-123,844.50	-422,777
9	-292,146	-6,786	-123,844.50	-422,777
10	-292,146	-6,786	-123,844.50	-422,777
11	-292,146	-6,786	-123,844.50	-422,777
12	-292,146	-6,786	-123,844.50	-422,777
13	-292,146	-6,786	-123,844.50	-422,777
14	-292,146	-6,786	-123,844.50	-642,509[51]
15	-292,146	-6,786	-123,844.50	-422,777
16	-292,146	-6,786	-123,844.50	-422,777
17	-292,146	-6,786	-123,844.50	-422,777
18	-292,146	-6,786	-123,844.50	-422,777
19	-292,146	-6,786	-123,844.50	-422,777
20	-292,146	-6,786	-123,844.50	-196,215[52]
CUM TOTAL	-5,842,920	-135,720	-2,476,890	-8,455,530
			Initial capital costs Gen	**-1,132,812.50**
			Initial capital costs PV	**-4,523,277.12**
			NPV @ 6.1%=	**-10,637,949.26**

Table 9. Net Present Value of the Third Alternative.

H. COMPUTE THE NET PRESENT VALUE OF EACH ALTERNATIVE

Step 7 of a CBA requires the analyst to compute the NPV of each alternative analyzed. NPV is computed by taking the difference between the PV of benefits and the

[50] Cost of new batteries incorporated.

[51] Ibid.

[52] Salvage value of both generators and PV systems incorporated.

PV of costs.[53] In this CBA we did not gave values to the benefits so the costs only count as results. We have to pick one alternative with the highest NPV (the one with the lowest cost). A summary of the NPV of each alternative is included in the following table:

	Benefits	Costs	NPV
Alternative One	0	**--22,222,304.02**	**--22,222,304.02**
Alternative Two	0	**-17,733,629.37**	**-17,733,629.37**
Alternative Three	0	**-10,622,339.14**	***-10,622,339.14***

Table 10. NPV of Each Alternative.

I. CONCLUSIONS AND RECOMMENDATIONS

Step 8 of a CBA requires the analyst to make a recommendation based on the NPV. Boardman recommends that the analyst adopt the project with the largest NPV.[54] Using Boardman's method, alternative three had an NPV of -10,246,448.56 and could be the winning solution.

It is obvious that the third alternative which uses PV as primary system for energy production is the one with the greater potential to supply the off grid islands with the required energy. The concurrent use of diesel generators as a secondary method of emergency energy production ensures that there will be no failures to the system. This along with the cost reduction and environmental benefits that the use of PV ensures make the third solution ideal for implementation on the off grid sites.

[53] Boardman Anthony et al., Cost-Benefit Analysis: Concepts and Practice, Second Edition. New Jersey: Prentice Hall, 2001, p. 10.

[54] Ibid., 11.

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VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The cost for electricity production in the majority of the remote off grid Aegean islands of Greece is extremely high due to the aged autonomous diesel power generators that are used. More precisely, the electricity production cost for a medium size Aegean island is approaching the value of 1€ per KWh and in some cases is even higher. The fuel cost represents almost 50% of the cost of electricity.

Moreover, in all these cases, the fuel transportation is very difficult, especially during the winter. During the summer, the maximum available power of the local grids is often less than the demanded load, leading to electrical black outs. This energy shortage is one of the principal factors that delays the economic development of the local societies and lowers the life quality level of the habitants, resulting in the abandonment of many of those islands.

All of these islands have an excellent PV potential providing them with the capacity to meet all of their power needs via use of Photovoltaic power parks. However, fluctuations in the daily and the seasonal electricity demand in almost all the island grids and the inability of PVs to produce electricity during the night, in conjunction with high initial investment of a PV park make the power production decision more complex and challenging.

In order to face these problems, this study examined the possibility to create a combined Hybrid PV-diesel energy station on a techno-economic basis. According to the study's results, the proposed hybrid project is the best possible method to cover the local electricity demands for the majority of the Aegean Archipelago islands, at least in a short term scenario basis. The simplicity in installation, maintenance and operation cost, provides a reliable power solution and lowers Greek dependence on imported fuel.

The results of current PV capabilities and recent technological advances are very encouraging. Furthermore PV technology has the potential to reduce electrical demands

on the local power grid, reduce the dependence on imported fuel and lessen the negative environmental impacts. For all these reasons it can be easily seen that PVs improve the economic development and improve the quality level of life of the local societies.

According to the results from the above analysis and the legislation regarding the use of PV energy (RES) in Greece, the use of PV applications proves to be economically beneficial and viable.

The total benefits by the use of PVs overweigh the total costs, especially those attributed to the initial investment. The benefits that derive from the introduction of the PV systems in the Aegean islands are:

- The country in general becomes less dependent on the import of oil which in turn has long term effects. Many of the indicators of the Economy are influenced by oil. The less dependence the country is on oil the more the stability the economy has because it stops being subject to a volatile factor. The Public Power Company will be able to conduct a long term planning to achieve a stable price for the kWh, since this price will not be based on the import of a primary product such as oil.
- Under the new regulations imposed by the Kyoto protocol the excessive amount of emissions is penalized with a tariff which is decided by the market for permits. Disengagement from traditional fuels will relieve the country from the need to participate in the international market for permits and save tremendous amounts of money. Moreover, a shift to a PV will allow Greece to achieve a desirable 20.1% RES energy production rate by 2010.
- Among all sources of energy the Solar PV systems provide maximum potential benefits. PV have high energy output, are simple to install and maintain, reduce dependence on imported fuel and facilitate the development of local economies in off grid islands.
- The introduction of the PV systems in the production of energy on the Aegean islands not only can save substantial amount of diesel, but can also avoid excessive wear and tear of the already existing Diesel Generator sets. This results in lower ownership costs and potentially increases the useful life of the generators.
- In the case of a typical Aegean island, with a peak demand of approximately 3MW, the use of PV causes substantial benefits since the savings from the avoidance of the use of oil are important.
- The introduction of PV technology creates new jobs in the areas of the Aegean island, which is beneficial to their already stressed economies.

- There are significant environmental advantages in the form of reduced carbon dioxide emissions due to the lesser load on the Diesel Generator sets. According to the most optimistic scenarios, the average temperature in the Aegean islands during the summer will raise 7-8 ^{0} C by the end of the century. The reduction of the CO_2 emissions will alleviate the already overstressed local ecosystems and provide more humane conditions for the habitants of these islands.
- The combination of the new favorable legislation for the application of RES, with the use of advanced technological systems provides entrepreneurs with new investment opportunities in the energy sector. The incentives as demonstrated in the case study in the Appendix of Amorgos Island are high and may encourage further economic investments.
- The preceding cost benefit analysis demonstrates the potential superiority of PV applications. Accordingly, the incorporation of the PVs in conjunction with the use of Diesel Generators provides numerous benefits. This hybrid approach has the lowest life cycle costs. In the case of newly powered islands the PVs should be the primary source of energy and the DG the secondary one though the latter may appear as initially less expensive.
- For high solar radiation areas, like the Aegean islands, PV are characterized as economically attractive investments, especially if the subsidization opportunities by local authorities are taken into consideration. Thus, according to the results obtained in the Appendix, the authors believe that an autonomous photovoltaic system can definitely contribute to solving electrical production needs of remote off-grid islands. The increased reliability of PV systems could improve the quality of life for many island inhabitants

B. RECOMMENDATIONS

This project evaluated current policy in the energy sector and conducted a cost benefit analysis for the implementation of photovoltaic energy at the Aegean Islands. As a result of this analysis the following actions are recommended to improve PV implementation and overall energy strategy in the off-grid islands.

1. Verify the Results of the Atira PVPC System

It is recommended that the results of the new PVPC system be verified at the remote islands of Greece. Final test results will provide a solid base for a more accurate

cost benefit analysis and facilitate more informed energy investment decisions. These tests will also serve to provide the entrepreneurs a starting point for future PV project proposals.

2. Implement a Photovoltaic PV Project at a Remote Off-Grid Island

The analysis supports the installation of a photovoltaic energy generation system at an island with already existing DG systems. It is recommended that once the entrepreneur has verified the results from the testing they should solicit proposals for a PV system in the Aegean islands.

3. The Public Power Company

The Public Power Company should incorporate the new PV technology in its future projects so as to alleviate the burden from its existing DG systems. With the reduced installation cost that the PV system offers the benefits could be substantial for the PPC.

4. The Gradual Replacement of the Already Existing DG Systems

The Public Power Company should gradually replace the already existing and aging DG systems starting from the far remote islands at first, due to the greater cost of oil transportation and then to proceed with the nearest ones. This will greatly enhance the savings associated with reduced oil transportation costs.

5. Simplification of the Procedures

The Greek government ought to simplify the procedures required to gain a license to install PV systems and also minimize the time needed to do so. The current time period of nearly 305 days to acquire the necessary license is a disincentive for potential entrepreneurs that might be willing to undertake such projects. A possible reduction of this time period might boost the demand for especially small to medium scale projects on the off grid islands.

C. AREAS OF FURTHER RESEARCH

During the course of this research the following topics that were outside the scope of this project and would require further examination to fully understand their impact on the development of a viable and ambitious overall strategy to cope with the energy question in the Aegean.

- Perform a cost benefit analysis and a business plan comparing the installation of PV systems with the installation of high voltage subterranean wires. The installation of such equipment is desired by the local communities because of its reliability. Nevertheless it is not always a profitable solution and it is sometimes prohibited because of the distance of the islands from the mainland
- Perform a cost benefit analysis and a business plan for large scale projects regarding the bigger islands of the Aegean, such as Rhodes and Crete with a peak demand of more than 100MW. These islands have a great PV potential due to their geographical position at the southern part of the Archipelago.
- Perform a life cycle cost analysis regarding both diesel generators and PV systems. This will provide with a better understanding of the two solutions and will lead to better informed investment decisions. Additionally, it will bring to surface the advantages of the PV systems and become a tool for the selection of the appropriate method of electricity production, according to the scale of the investment.

D. SUMMARY

This study has examined solar energy and its potential to generate electricity. In addition to its low cost solar energy is meant to be a viable solution to eliminate climate change due to the green house effect. According to scientists, the mean temperature in the Aegean will raise 7-9^0 C by the end of this century. Moreover, most experts agree that the world has between thirty to fifty years of petroleum reserves left. We need to start introducing renewable energy technologies in our energy production systems as soon as possible. Photovoltaic systems will become more popular and widespread over the years to come as people look for ways to economize and help the planet's environment at the same time.

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APPENDIX. BUSINESS PLAN FOR AMORGOS ISLAND

A. ABSTRACT

The new legislation for the renewable energy sources in Greece stages a new business environment for entrepreneurs to use their assets in order to establish new corporations in the energy sector. The feed-in tariffs provided by the state under the provisions of the Law 3468/2000 and the subsidies for the establishment of a new business in certain areas of Greece under Law 3299/2004 are an incentive to create new Photovoltaic installations on the off grid islands of the Aegean. The new feed-in tariffs and the obligation of the Operator to absorb any power produced by Renewable Energy Sources make plausible the production of energy and its subsequent selling associated with the electrification of the off grid islands. To test the plausibility of such an attempt we estimate the profitability of a business plan in terms of its Payback time, Net Present Value (NPV) and internal rate of return (IRR), on the island of Amorgos which is off grid and with a relatively high peak demand of 2.9MW. The prices are in euros and taken after personal communication with certain equipment providers in Greece. Our installation is meant to feed the grid directly with the produced energy and there is no storage capacity for electricity. The financial sources are a company's internal equity and the State subsidy. We assume that we own the land for the installation. The calculations take into consideration a life span of 20 years.[55]

First we calculate the NPV of the project by using conventional-MPPT PV panels and then we calculate the NPV of the same project by using a new technology system. A comparison of the two NPVs is presented after the calculations.

[55] The methodology of the calculations is taken from the MBA Professional report: Operation Solar Eagle by C. Austin, R. Borja and J. Philips, Naval Postgraduate School.

B. COST CALCULATIONS

1. Maximum peak demand for Amorgos Island: **2,900,000W.**[56]

Per Figure 9, the average low peak sun hours for the desired area to use solar energy is 3.5h.

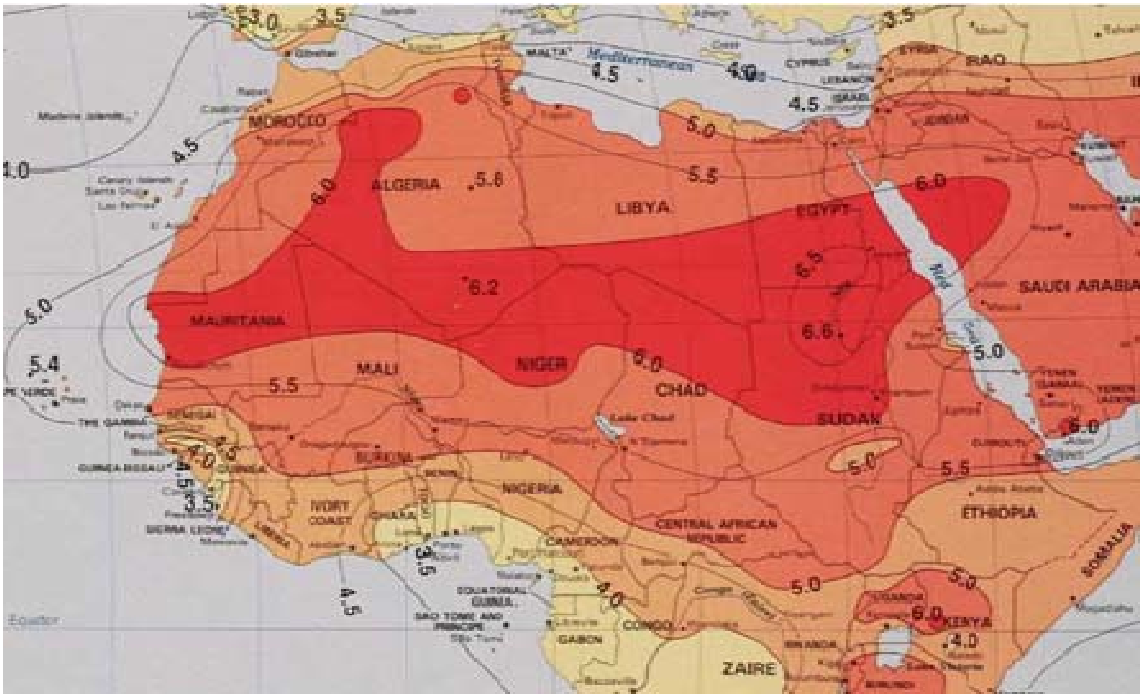

Figure 9. Solar map of Mediterranean[57]

2. We divide the actual power load with the average low peak sun hours and we have the result of 2,900,000/3.5= **828,571.42W**.

3. The solar panel to be used is Sharp 175 with a nominal capacity of 175 W/m^2. We multiply the nominal capacity by 0.8 for 80 per cent efficiency and we have: 175*0.8=**140W.**

4. We divide the outcome of step 2 by the actual capacity of the panel from step 3 and we have the total number of the panels to be installed:

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56 Personal Communication on 15 February 2007 with Director of Amorgos Island PPC Branch.

57 Solar4power, http://www.solar4power.com/map9-global-solar-power.html, Last Accessed: January/2007.

828,571.42W /140W=**5918.36** panels and approximately 5 to 6 acres of land.

5. Unit cost of the panel is 643.8 euros according to personal communication with manufacturers in Greece. We multiply cost per unit with number of units and we have the total cost of the panels: **5918.36***643.8=**3,810,244.9** euros.

6. Using 10KW inverters for the power load of 828.5711KW we have a 83 TOTAL of inverters. Unit cost of a 10KW inverter is 5600 euros so the total inverter cost is **464,800** euros.

7. Installation costs: **10,000**

8. Structure costs: **10,000**

9. Data controller: **500**

10. Consulting services: **3,000**

11. Civil works: **5,000**

12. Total costs: ***4,303,544.9***

13. With a subsidy of 50% of the project the total initial capital outflow is: ***4,303,544.9*0.5=*****<u>*2,151,772.45 euros*</u>**

All the costs along with the percentage of the subsidies that are offered by the State are summarized in the following table:

Total budget to be paid by the Ministry of Development			
	Initial prices	Subsidy percentage	Subsidy
5918.36 pcs Phot. Panels (sharp 175)	3,810,244.9	50%	1,905,122.45
83 pcs Inverters	464800	50%	232400
Structure	10,000	50%	5000
Installation	10,000	50%	5000
Data Controller	500	50%	250
Connection to PPC			0
Sub-total	4,295,544.9	50%	2,147,772.45
Consulting services	3,000	50%	1500
Civil works	5,000	50%	2500
TOTAL	4,303,544.9		***2,151,772.45***

Table 11. Total subsidies paid by the Mod.

The total energy produced during a year is 2.9MW*365days =1058.5 MW sold by 500 euros per MW. The total inflows during a period of 20 years are summarized in the following table:

Revenue Estimation

Totally produced energy	**Availability**	**Available energy**	**Losses**	**Offered energy**	**Percent. of shadow**	**Final offered energy**	**Selling price per KW**	**Revenue from energy sales**
1058500	100%	1058500	5%	1005575	2.00%	985463.5	0.5	492731.8
1058500	100%	1058500	5%	1005575	2.00%	985463.5	0.5	492731.8
1058500	100%	1058500	5%	1005575	2.00%	985463.5	0.5	492731.8
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1058500	100%	1058500	5%	1005575	2.00%	985463.5	0.5	492731.8
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1058500	100%	1058500	5%	1005575	2.00%	985463.5	0.5	492731.8
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1058500	100%	1058500	5%	1005575	2.00%	985463.5	0.5	492731.8
1058500	100%	1058500	5%	1005575	2.00%	985463.5	0.5	492731.8
1058500	100%	1058500	5%	1005575	2.00%	985463.5	0.5	492731.8
1058500	100%	1058500	5%	1005575	2.00%	985463.5	0.5	492731.8
21170000		**21170000**		**20111500**		**19709270**		***9854635***

Table 12. Total inflows during the life cycle of the project.

C. CALCULATION OF THE PROJECTS PARAMETERS

Payback time: The initial capital outflow is 2,151,772.45. We have a constant inflow of 492,731.8 each year .For the first 4 years of the project we have a total inflow of 1,970,927.2. The rest of the total initial capital outflow is 180,845.25. We divide this number by the annual inflow and we add it to the 4 years to calculate the payback time: 180,845.25/492,731.8=0.367. 0.367+4 = ***4.367 years.***

Net Present Value: It is important to calculate a realistic discount rate for the project because this parameter affects the outcome significantly. According to the current loan rate *i* offered to corporations by the Greek banks, which is 6.5%, the discount rate is calculated by the formula:

d= *i /1+i= 6.5%/1+6.5%=0.061* or **6.1%.**

We calculated the NPV with this discount rate and with one of **10%.**

First scenario:

Capital outflow: 2,151,772.45 euros

Annual capital inflow: 492,731.8

Discount rate: **6.1**%

NPV1: ***3,454,227.11 euros***

Second scenario:

Capital outflow: 2,151,772.45

Annual capital inflow: 492,731.8

Discount rate: **10%**

NPV2: ***2,043,131.13***

Internal rate of return:

Capital outflow: 2,151,772.45

Annual capital inflow: 492,731.8

IRR: 23%

The project seems to be profitable with a positive NPV and a satisfactory IRR The discount rate seems to be a crucial factor though for the final decision. However, the new system of tariffs encourages further investments in the Renewable Energy sources and especially in the photovoltaic installations.

D. RESULTS WITH THE PVPC SYSTEM

The results for the NPV with an advanced technology that is in the testing phase are depicted below. As a result of the installation of this unit we accept a 98.5% efficiency of the panel power rating.[58]

[58] W. Barich, B. Dessing, A. Harley, "A Case Analysis of Energy Savings Performance Contract Projects and Photovoltaic Energy at Fort Bliss, El Paso, Texas," MBA Professional Report, Naval Postgraduate School, p. 52.

The output of the Sharp 175W panel with 98.5% efficiency is 172.375 W. According with the sequence of the calculations in the previous example, the number of the panels required will be **4806.795** and 4.5 to 5 acres of land. The cost of the panels will be **3,094,615.114** euros. Accordingly the total cost will be **3,587,915.114** euros and with a subsidy of 50% the total initial capital outflow will be **1,793,957.557** euros.

Given the same stream of inflows from energy sale to the main grid, the Payback time will be **3.64** years. NPV for the project will be **3,812,042.00** euros at a discount rate of 6.1%. IRR of the project will be **28%**

E. COMPARISON OF THE RESULTS

With the use of the advanced technology system we have a significant improvement in the economic parameters of the project. The differences are summarized in the following table:

	Payback time(years)	**NPV (euros)**	**IRR**
Conventional Solar Array	4.367	3,454,227.11	23%
Advanced system	3.64	3,812,042.00	28%
Difference	-0.727	+357,814.89	+5%

Table 13. Comparison of Financial Criteria of the two projects.

The incentives for the entrepreneur to adopt and install new technologies are obvious. The combination of the new technology along with the incentives provided by the State with the feed-in tariffs, present a good opportunity for further investment in the Photovoltaic applications in Greece. The following chart demonstrates the superiority of the advanced system compared to a conventional PV system at any value of the discount rate from 0.0% - 12.0% in terms of NPV.

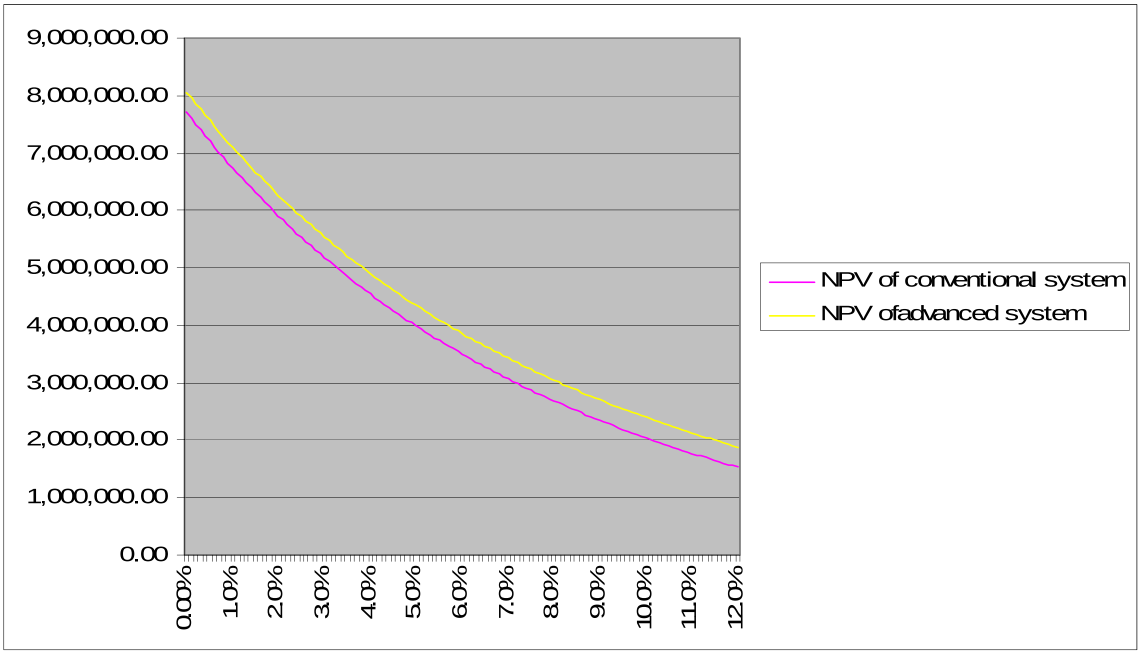

Table 14. NPVs of the two systems according to variations of the discount rate.

Clearly, the application of advanced technologies can provide returns. Any installation of PV systems should include advanced technologies whenever the returns on investment justify their use.

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